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ANALYSIS OF HELICOPTER STRUCTURAL CRASHWORTHINESS

VOLUME II. USER MANUAL FOR "CRASH", A COMPUTER PROGRAM FOR THE RESPONSE OF A SPRING-MASS SYSTEM SUBJECTED TO ONE-DIMENSIONAL IMPACT LOADING (UH-1D/H HELICOPTER APPLICATION)

By

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January 1971

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-69-C-0030
DYNAMIC SCIENCE (THE AvSER FACILITY)
A DIVISION OF MARSHALL INDUSTRIES
PHOENIX, ARIZONA

U S ARMY MATERIEL COMMAND

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This report was prepared by Dynamic Science (The AvSER Facility), A Division of Marshall Industries, under the terms of Contract DAAJ02-69-C-0030.

The purpose of this effort was to (1) document and classify the most hazardous factors concerning airframe crashworthiness, (2) seek methods of reducing vertical decelerations at the floor level in potentially survivable crashes, and (3) seek design methods for maintaining the "protective shell" around the occupants in an accident. The contractor achieved these objectives by conducting a study of 43 major accidents involving the UH-1D/H aircraft to determine what types of structural failure were contributing to injuries in helicopter accidents and by developing, programming, and verifying a 23-degree-of-freedom, nonlinear lumped mass mathematical model. This model was then used in a parametric study of the UH-1D/H aircraft to evaluate potential areas of crashworthiness improvement. This report contains a description of the accident data study, mathematical model, parametric study, full-scale drop test, and the results obtained.

The conclusions and recommendations submitted by the contractor are considered to be valid; however, the mathematical model developed has definite limitations, the most critical limitation being that the model considers only vertical impact loads and therefore does not consider the longitudinal and lateral components that are usually also present in the helicopter crash environment. A second limitation is that it would be extremely difficult to use this approach to model and analytically study the crashworthiness of future aircraft designs with any confidence. This is due to the problems that would be encountered in attempting to predict the necessary weight data to apply to the lumped mass simulation and the spring constant data necessary to apply to the various springs that connect the masses of the model.

It is the intent of this Command to expand this mathematical model to include dynamic response to combined crash loading; i.e., crash loads which possess vertical, longitudinal, and lateral components, thereby developing a more realistic and useful analytical tool.

This report is divided into two volumes. Volume I contains a description of the accident data study, mathematical model, parametric study, full-scale drop test, and the results obtained. Volume II is a user manual for the computer program developed.

SUMMARY

A mathematical model which may be used to determine the dynamic response of a helicopter airframe subjected to vertical crash loading has been developed.

This report is, in effect, a manual which will facilitate the use of the computer program "CRASH". The program was written to solve the equations and to handle the nonlinearities and constraints which result from use of the mathematical model.

The program was used to evaluate the response of the UH-1D/H helicopter to vertical impact loadings. Recommendations have been made which, when implemented, will reduce the forces transmitted to the floor and transmission of the aircraft.

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Final Report

AvSER Report 1520-70-31

By

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for

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FORT EUSTIS, VIRGINIA

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INTRODUCTION

This "User Manual" provides the details and fundamental concepts required to execute "Program CRASH" in a productive manner. The mathematical background for Program CRASH is contained in Vol. I of this report.

Program CRASH is a computer simulation of a general rotary-wing aircraft. It represents an attempt to provide the engineer with a practical tool for investigating the dynamic response of such a structure when subjected to vertical crash conditions.

It is very important that the user understand the model description and limitations. As would be expected, the model's geometry, physical characteristics, and structural properties can be quite extensive. To facilitate the user's understanding of the program an example problem is demonstrated, illustrating the type of problem which can be solved. In this example, the generalized model is adjusted to represent the Army's UH-ID/H aircraft. The numerical input is discussed in detail. Representative output printer plots, directly from the computer, are also included to further illustrate the type and format available to the user.

Although most users will be interested in the attenuation of acceleration levels at particular locations due to the non-linear deformation of the structure, the available output is not so limited in scope. Velocities, absolute and relative deformations (both linear and angular), forces, bending moments, and the concept of energy absorption are also available output features.

The output takes three forms: a tabulation of input data, a tabulation of output parameters at selected time increments, and combination tabulation-plots of output parameters called for through the input. Dummy input coding sheets are also included to assist the beginning user in organizing the input.

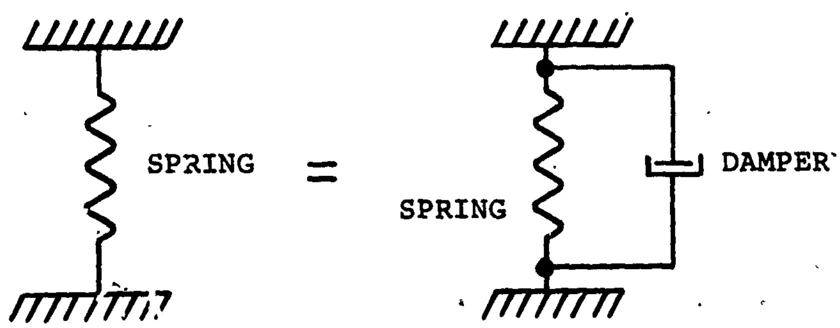
MATHEMATICAL MODEL DESCRIPTION

GENERAL

The mathematical model used in this study represents the airframe structure of a rotary-wing type aircraft. It is a nonlinear lumped mass model having 23 degrees of freedom. To construct the model, the airframe structure is divided into four vertical and three longitudinal sections as shown in Figure 1. Individual masses are identified by number in Table I. The vertical section divisions are (1) transmission, engine, and rotor section, (2) mass above the floor section, (3) mass below the floor section, and (4) landing gear section. The longitudinal section divisions are (1) nose section, (2) central section, and (3) tail section. The 14 masses are spring connected into the model and are used to represent various sections of the airframe structure. Springs connecting the masses are shown in Figure 2 and identified in Table II. The vertical section masses permit a parametric study of the distribution of the load-limiting properties throughout the important vertical sections of the airframe structure. The longitudinal masses, shown in Figure 3, permit a study of plastic hinges and shear failures at four simulated airframe locations. All masses may not be required to represent a particular section of the airframe structure under study; however, the model is generalized to the degree that single- as well as multi-engine aircraft may be analyzed.

VERTICAL SECTION DESCRIPTION

The masses representing the four vertical sections, when connected into the model, simulate load-deflection characteristics. They are connected into the model with 16 direct- and seven far-coupled springs. Each spring is combined in parallel with a damper as shown below.



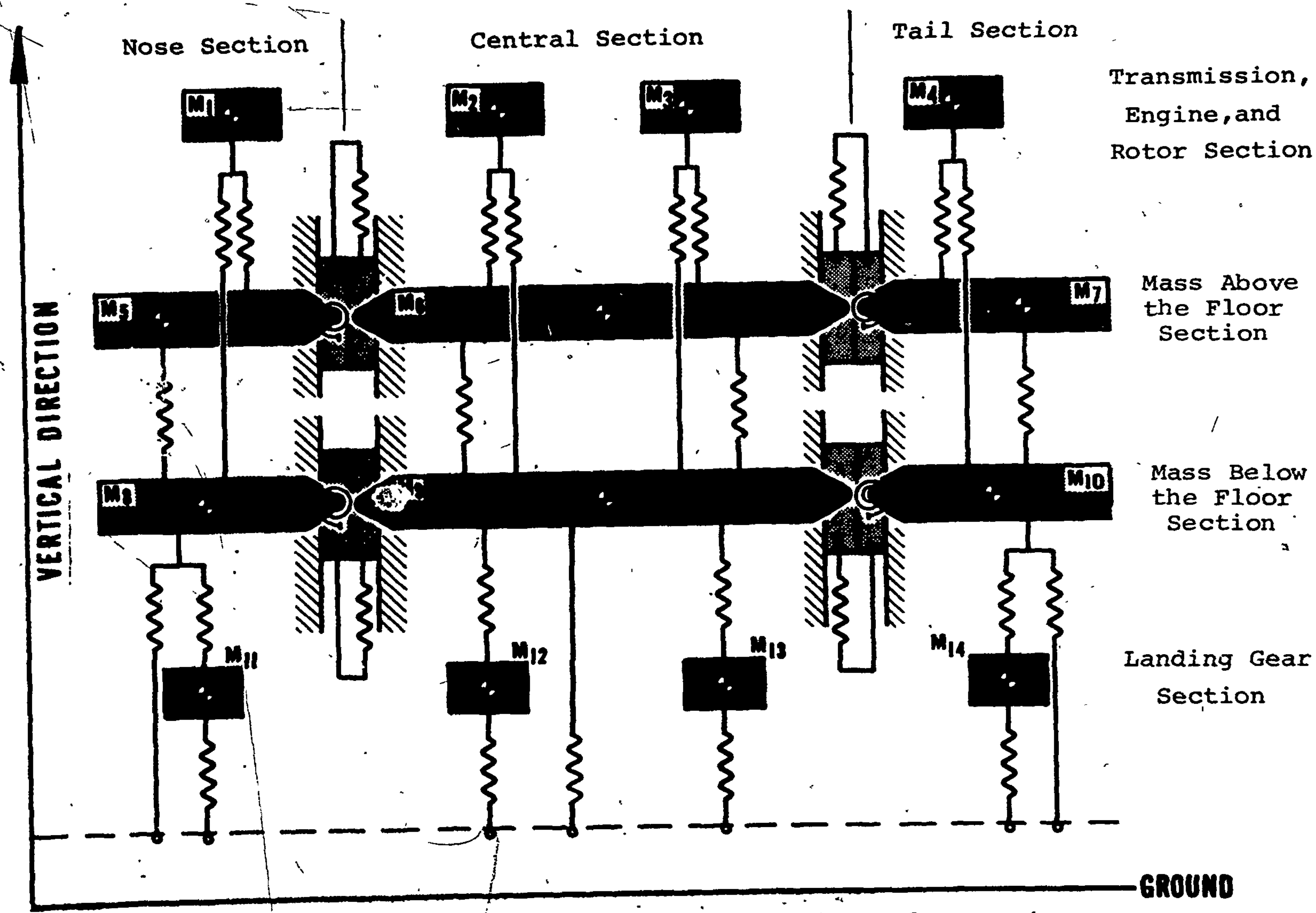


Figure 1. Model Description (Lumped Masses).

TABLE I. MODEL DESCRIPTION (LUMPED MASSES)	
Mass No.	Description
M1 M2 M3 M4	Rotor Assembly, Transmission Assembly, and/or Engine Assemblies
M5 M6 M7	Airframe Structure Above Floor Level
M8 M9 M10	Airframe Structure Below Floor Level and Floor Dead Loads
M11 M12 M13 M14	Landing Support System

The viscous damping is assumed to be proportional to velocity.

Two types of spring damping are considered in the model: internal (hysteresis) damping and external (viscous) damping. Internal damping is introduced into the model through the load-deflection curve shown in Figure 4. By assigning different slope values to the unloading portion of the generalized load-deflection curve, a hysteresis cycle can be generated which will absorb energy. The degree to which the load-deflection curves will reproduce the aircraft structure is dependent upon the quality of data available for the particular aircraft to be studied, and upon the user's ability to interpret available data and comprehend the dynamics of the deforming structure.

External damping is introduced by the use of a constant applied to the rate-of-change of spring deformation. The numerical value of this constant may be determined by an analytical

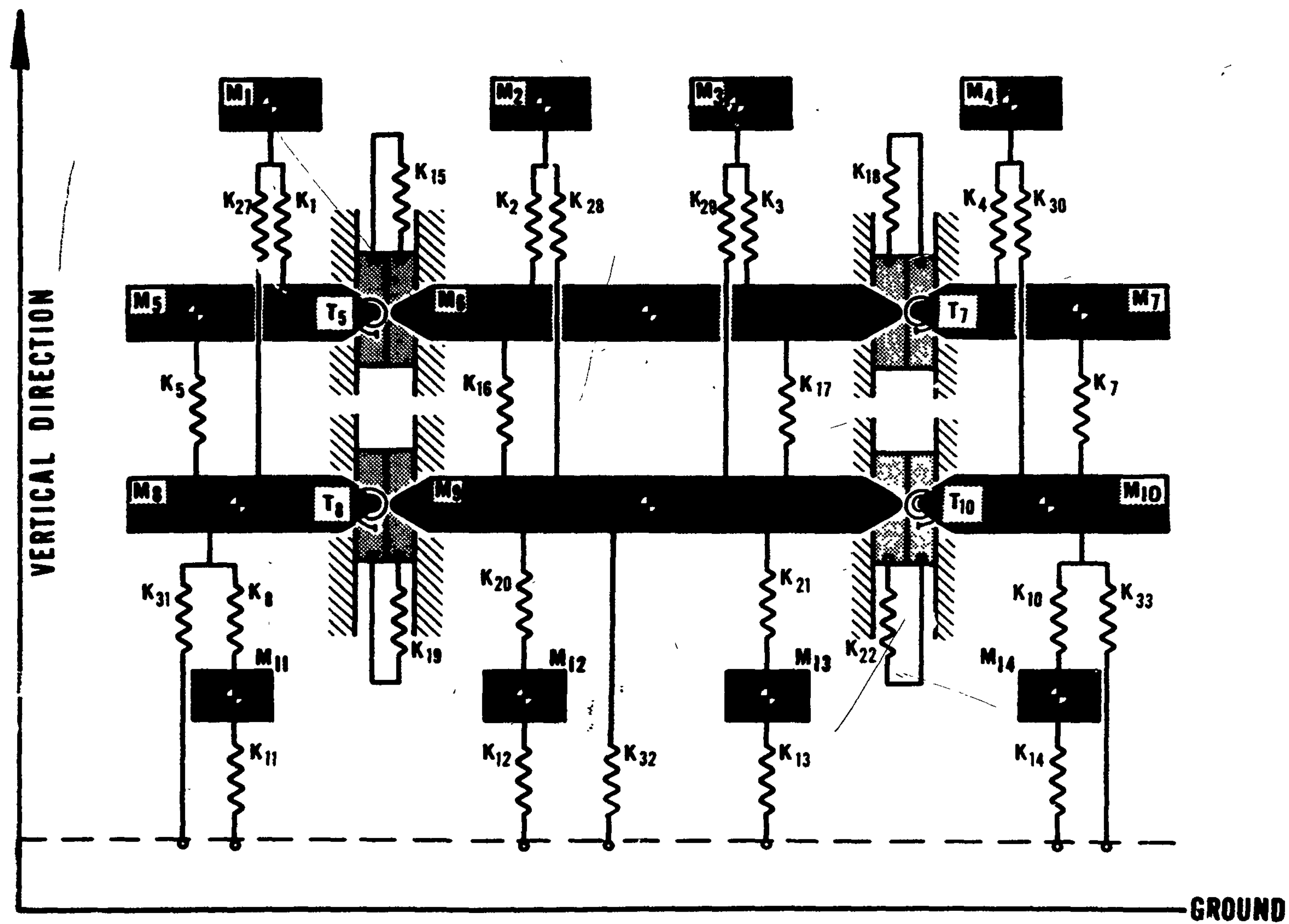


Figure 2. Spring Identification Diagram.

TABLE II. MODEL SPRING IDENTIFICATION	
Spring No.	Description
K1 K2 K3 K4	Direct-Coupled Load-Deflection Characteristics of Rotor/Transmission and/or Engine Support System to Upper Fuselage
K5 K7 K16 K17	Direct-Coupled Load-Deflection Characteristics of Airframe Structure Above Floor Level
K8 K10 K11 K12 K13 K14 K20 K21	Direct-Coupled Load-Deflection Characteristics of Landing Support System
K15 K18	Direct-Coupled Load-Deflection Characteristics of Airframe Structure Above Floor Level During Shear
K19 K22	Direct-Coupled Load-Deflection Characteristics of Airframe Structure Below Floor Level During Shear
K27 K28 K29 K30	Far-Coupled Load-Deflection Characteristics of Rotor/Transmission and/or Engine Support System to Floor

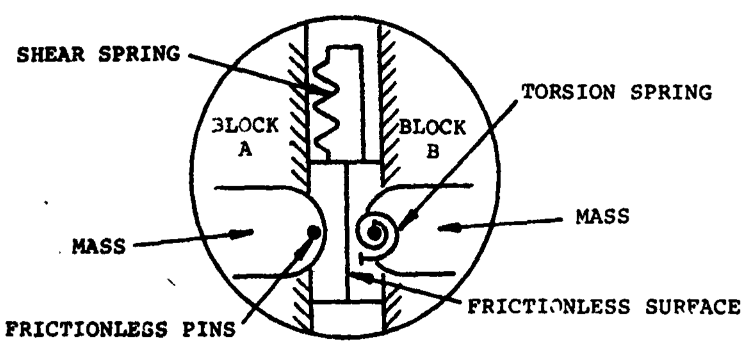
TABLE II. Continued	
Spring No.	Description
K31 K32 K33	Far-Coupled Load-Deflection Characteristics of Airframe Structure Below Floor Level
T5 T8	Torsional Load-Deflection Characteristics of Forward Fuselage Section
T7 T10	Torsional Load-Deflection Characteristics of Rear Fuselage Section

estimate, based on theoretical data, or by performing a series of computer runs using various estimated values for these constants and comparing the results to experimental data.

The extensional springs in the model are classified into two types, depending upon the ability of the structure represented to restrain a tensile rebound. A type 1 spring is one which can restrain tensile rebound, while a type 2 spring cannot. Refer to Figure 4 and the definition of SD(I,7).

LONGITUDINAL SECTION DESCRIPTION

The masses simulating the three longitudinal sections of the airframe structure are connected into the model with four torsional springs and four shear-type springs. Connection details are shown below.



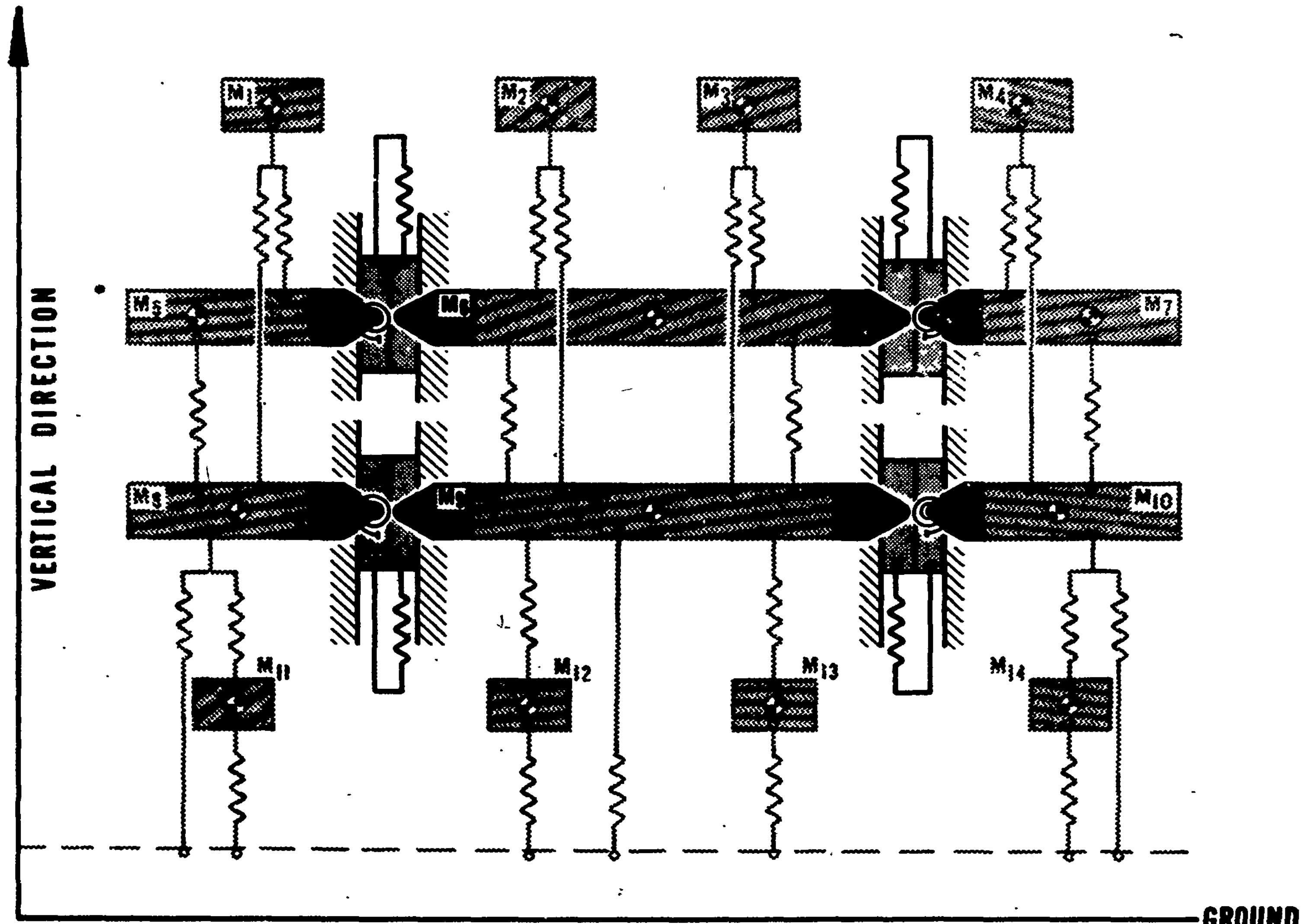


Figure 3. Longitudinal Section Spring Connection Diagram.

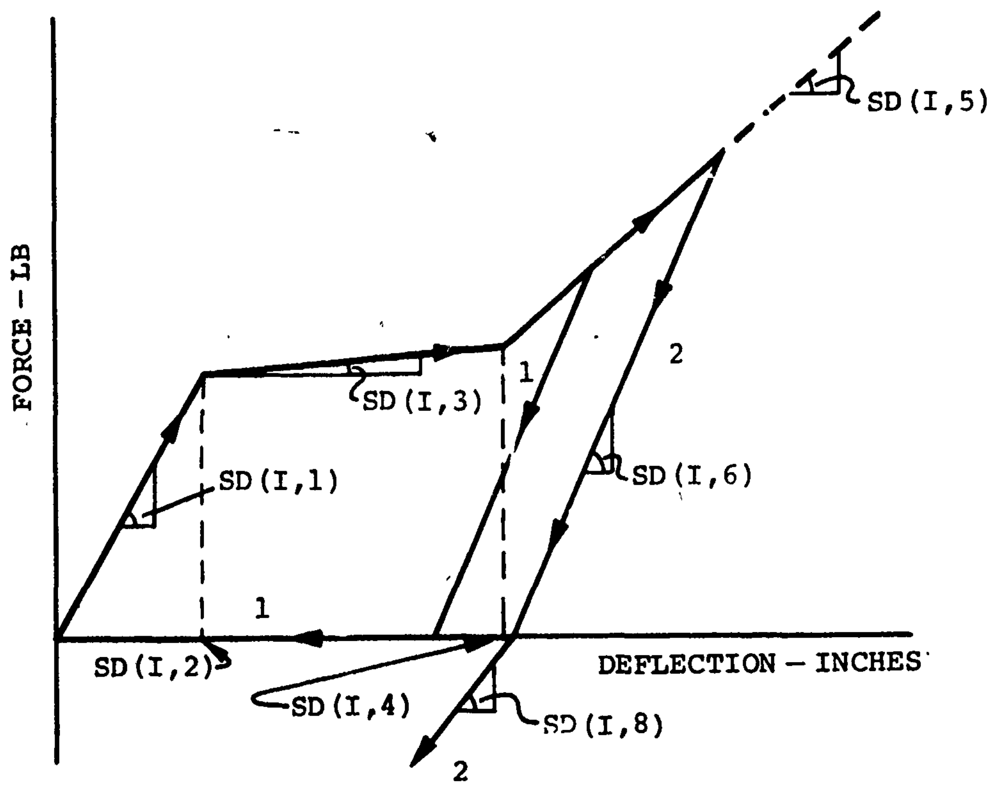


Figure 4. Description of Load-Deflection Curve.

PARAMETER	DESCRIPTION
SD(I,1)	Slope of linear elastic portion of curve.
SD(I,2)	Deflection which causes yielding to occur.
SD(I,3)	Slope of first plastic portion.
SD(I,4)	Deflection at which plastic slope changes.
SD(I,5)	Slope of second plastic portion of curve.
SD(I,6)	Unloading slope.
SD(I,7)	1 {Spring type}, Type "1" follows curve 1 2 {Spring type}, Type "2" follows curve 2
SD(I,8)	Proportionality constant for viscous damping (applies to entire curve).

The interface between blocks A and B is frictionless, permitting relative vertical displacements. The resistance against such a vertical displacement is provided by a shear spring. This simulates the possibility of a shear-type failure occurring in the fuselage, the severity of which is controlled by the shear spring. The two masses are connected to blocks A and B by frictionless pins, thereby permitting relative angles to form between the two masses. Resistance to such rotation is offered by the torsion spring. This simulates the formation of a plastic hinge in the fuselage. The generalized load-deflection curve used for all springs is shown in Figure 4.

MODEL DIMENSIONS

The general coordinates and model dimensions are shown in Figures 5 and 6. These dimensions and physical properties are consistent with the data provided in the Input Description section herein. If the application of the generalized model to a specific problem does not require all of the lumped masses, the weight of the omitted mass should be assigned a value of 1.0 pound and the dimensions describing its location omitted. If the omitted mass happens to be one which has rotational properties, its mass moment of inertia should also be assigned a nominal value of one unit.

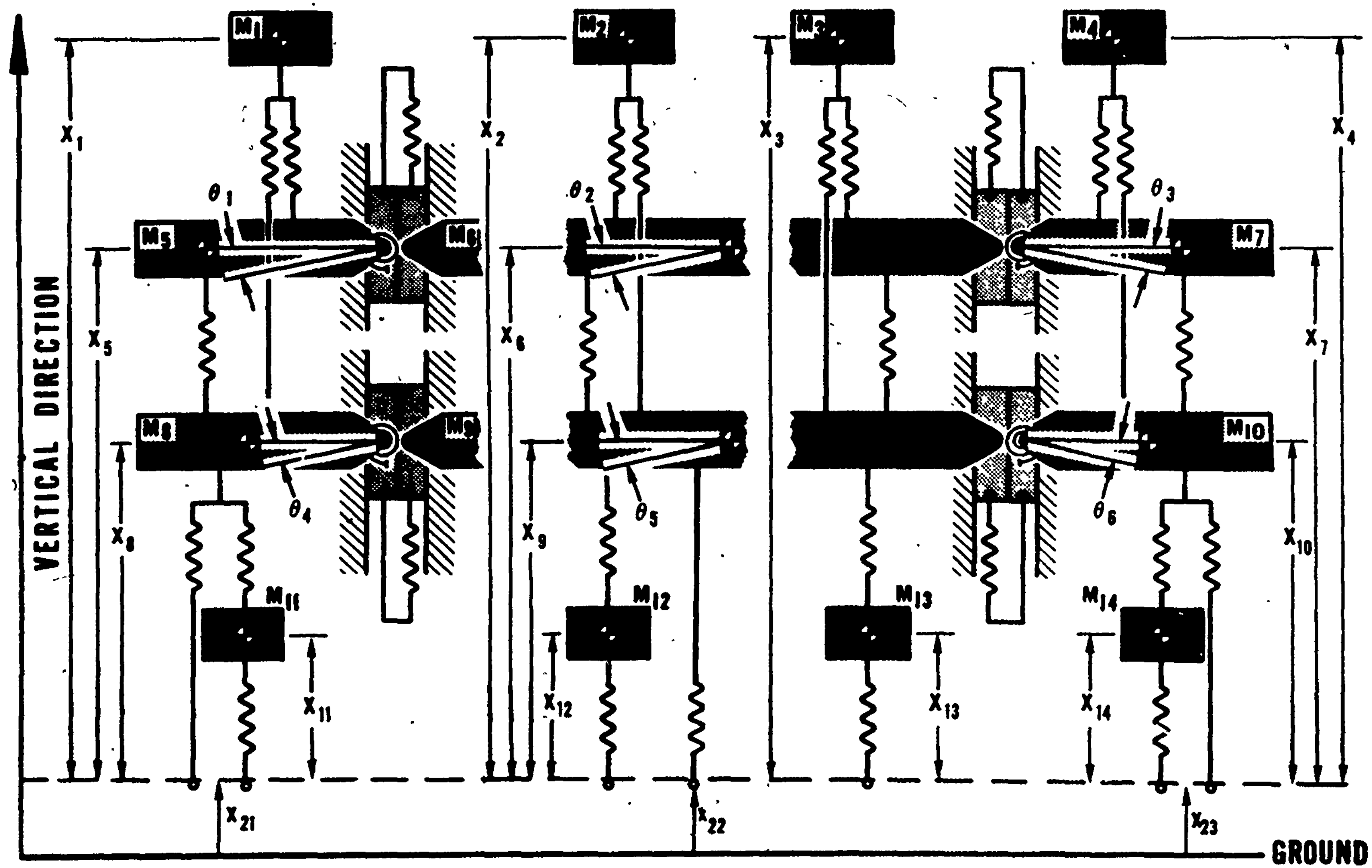


Figure 5. Model Coordinates.

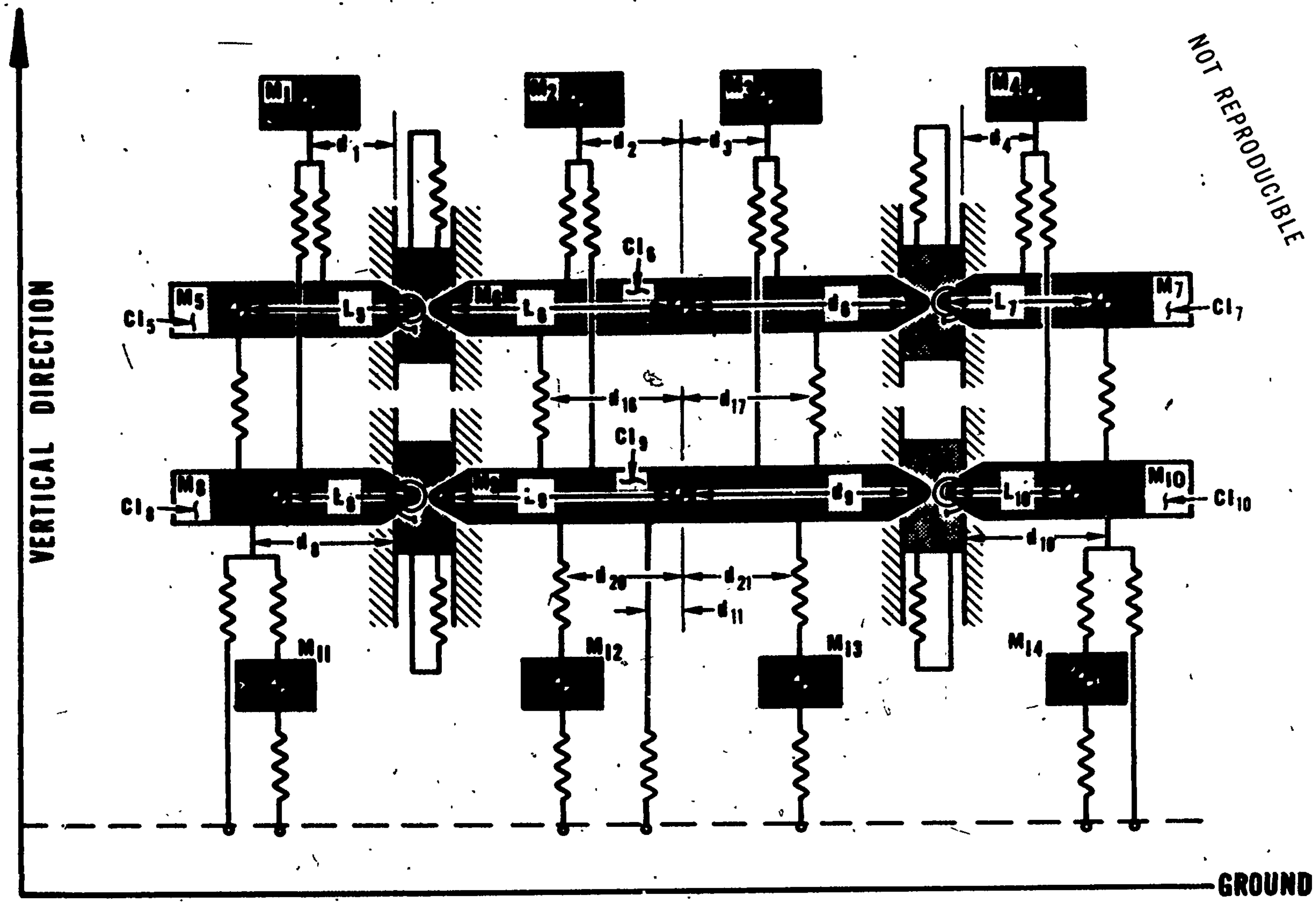


Figure 6. Model Dimensions.

PROGRAM DESCRIPTION

The computational scheme of Program CRASH is controlled by a small main program which calls upon 10 subroutines. Not only does the nature of the problem permit its dissection into input and output phases, but even the computational phase of the problem is uniquely suited for the building block technique provided by subroutines. This type of program structure also lends itself to overlay techniques if the user finds it necessary. Nine of the 10 subroutines are linked together by numbered common, using approximately 7,600 decimal locations. The plotting subroutine uses the formal call sequence to transfer data. The source deck is composed of 827 cards, requiring approximately 24,600 decimal core locations. The program as listed in Appendix I is compatible with an IBM 360-40 computer.

Data is read into the program in two locations. First, the main program is informed how many individual cases of data will be processed, and, thereafter, data is entered into the program only through subroutine "READ". The following section provides a detailed description of this subroutine. The input data can be grouped into four categories:

INPUT

1. Physical Properties: This involves the dimensions, mass distribution, and structure stiffness properties of the model. This group of input comprises about 90 percent of the input data.

2. Crash Conditions: The vertical velocity and pitch rates of all masses must be specified at impact, along with the ground conditions.

3. Output Requested: There are a possible 129 printer plots which can be requested. Of these parameters, as many as three may be plotted simultaneously on the same plot for comparison. This is the feature of the program which enables the engineer to analyze a large amount of data. The parameters to be plotted and their sequence must be specified. The details of this output feature and the required instructions are found in the Input Description section herein.

4. Numerical Integration: The total time duration of the numerical integration, T_{max}, and the delta time increment, DT, must be specified. The times for which the program stores data for future plotting must also be specified.

MODELING THE AIRCRAFT

The aircraft is modeled by dissecting it into its major structural or weight components. The generalized model, Figure 1, is composed of a number of lumped masses, defined by Table I, which are used to represent the major weight components of the aircraft. The plastic hinges provided by the model permit certain masses to break and rotate with respect to each other. The location of these plastic hinges is guided by the user's knowledge of the structure's ability to resist bending moments, or past accident histories of postcrash configurations. All of the lumped masses, 14 in all, may not be needed to properly describe a particular aircraft. In those cases where a mass is omitted from the generalized model, its weight, CM(I), must be assigned a nominal value of 1.0.

The load deflection characteristics of the model are represented by 33 nonlinear springs as shown in Figure 2 and Table II. The load deflection characteristics are assigned by the curve illustrated in Figure 4.

> Note: If a spring is to be omitted, the blank input card for that spring must be present in the input sequence. The program checks the spring-type parameter, SD(I,7), to see if the spring is present.

> Note: If the spring-type SD(I,7) = 0.0, the spring has been omitted from the program. If the spring-type SD(I,7) = 1.0, the spring is unable to hold a tensile load or to elongate. If the spring-type SD(I,7) = 2.0, the spring is capable of resisting a tensile load and may elongate.

The ability of the simulator to duplicate a crash condition depends upon the degree of realism that the user can incorporate into the model through the use of realistic load-deflection spring characteristics. The user is limited only by his ability to idealize desired nonlinear load-deflection properties by the series of straight lines provided by Figure 4.

An additional feature of Program CRASH is to limit the deflection of certain springs. This is accomplished by an adjustment to the elastic portion of the load-deflection curve when the spring exceeds the user-supplied limiting deformation value. This requires the numerical procedure to be stopped and re-started at a former time, extending the program both in complexity and computational time required for a run sequence. To help reduce the excessive time required, the number of restarts required should be reduced. Toward this end, the program is constantly projecting 50 time increments ahead,

estimating with the information on hand if these conditions will occur. If these projections indicate that the program will have to be re-started 50 time increments in the future, adjustments are initiated in an attempt to correct the situation before it happens. If the original load-deflection slope is too large, the projection will be conservative, thus decreasing the slope for the next iteration. If the slope is too small, the projection will indicate a future violation and the slope will be increased for the next time increment. The amount of increase or decrease in this slope is provided by the user. If the user supplies a very small delta slope change, the program may not be able to correct within the available 50 time increments, thus forcing a re-start condition. This condition will continue until the deformation limitations are achieved. This can develop into a rather time-consuming process, especially if there are more than three springs being limited. The beginning user is cautioned against excessive use of this program feature in the early stages of developing a particular model. Once an idea of the model's general behavior is obtained, the user should have a better idea of what restrictions to impose in this limiting process. The user is reminded that this technique does not provide a "unique" load-deflection curve which restricts the spring deformation within the desired range, since there are many possible curves which will satisfy the required condition. This technique determines one of the many possible answers.

<u>Note</u>: The program is written to handle up to 10 limiting springs simultaneously.

CRASH CONDITIONS

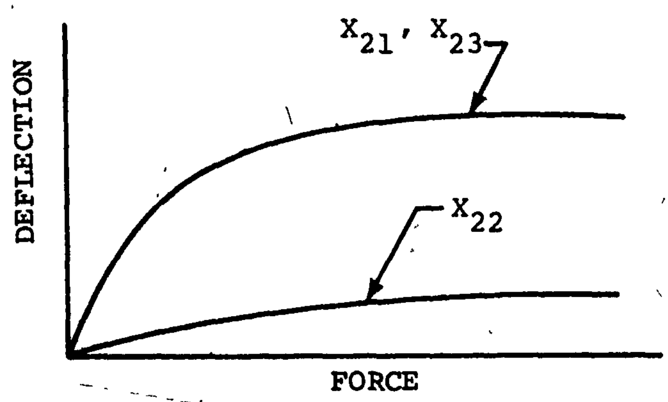
A vertical impact with a positive or negative pitch rate is permitted. Each single-degree-of-freedom mass is assigned an impact velocity in ft/sec. If the mass has rotational properties, the mass is given a vertical velocity and also a possible nonzero angular velocity. Whatever the velocity condition is at impact, it must represent a kinematically consistent system. The example provided represents the simplest system possible, namely, pure vertical input, all linear velocities being equal, and all angular velocities being zero.

GROUND CONDITIONS

The ground is modeled by a deflection-force equation of fourth order or less. For example:

$$\text{Ground Deflection} = GD(I,1)\ (\text{force}) + GD(I,2)\ (\text{force})^2 + GD(I,3)\ (\text{force})^3 + GD(I,4)\ (\text{force})^4$$

where I = 1, 2, 3 represents the three possible contact points between the fuselage and ground, X_{21}, X_{22}, X_{23}, of Figure 5. The deflection of the ground for the contact point may be quite high since a possible landing skid may produce high soil bearing stresses. However, when the fuselage contacts the ground, these soil bearing stresses are drastically reduced due to the large increase in bearing surface. The general example of this concept is shown by the following diagram:



The parametric study (Vol. I of this report) was performed assuming an infinitely rigid ground condition, attempting to approximate the worst condition.

OUTPUT

Full digital output is automatic. This is composed of the following information at each requested plot time:

1. Generalized coordinate motion, both vertical and angular, during impact, taken from a zero reference.

2. Vertical and angular velocities of each mass during impact.

3. Vertical and angular accelerations of each mass during impact.

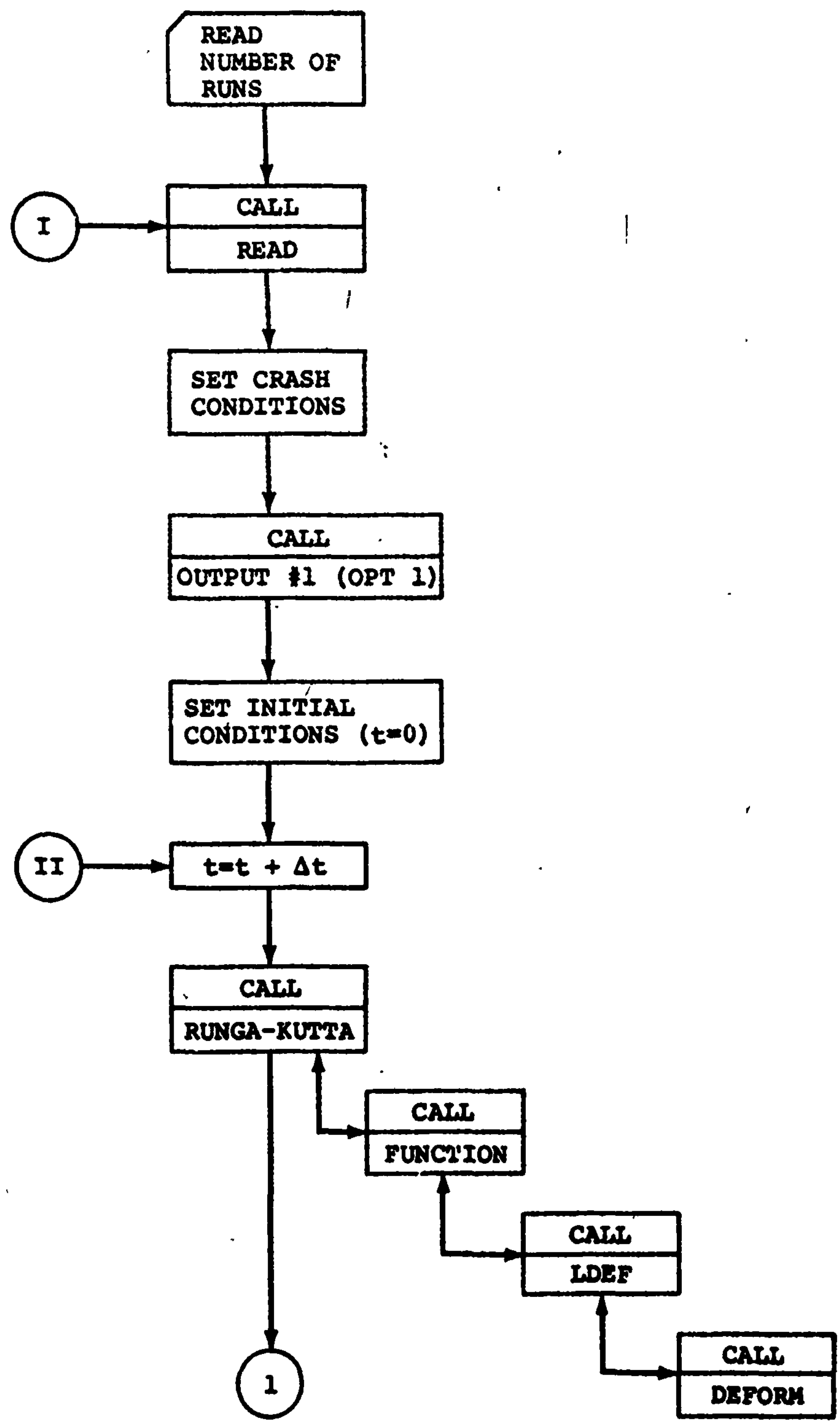
4. Relative spring deformation of each spring during impact.

5. The force in each spring during impact.

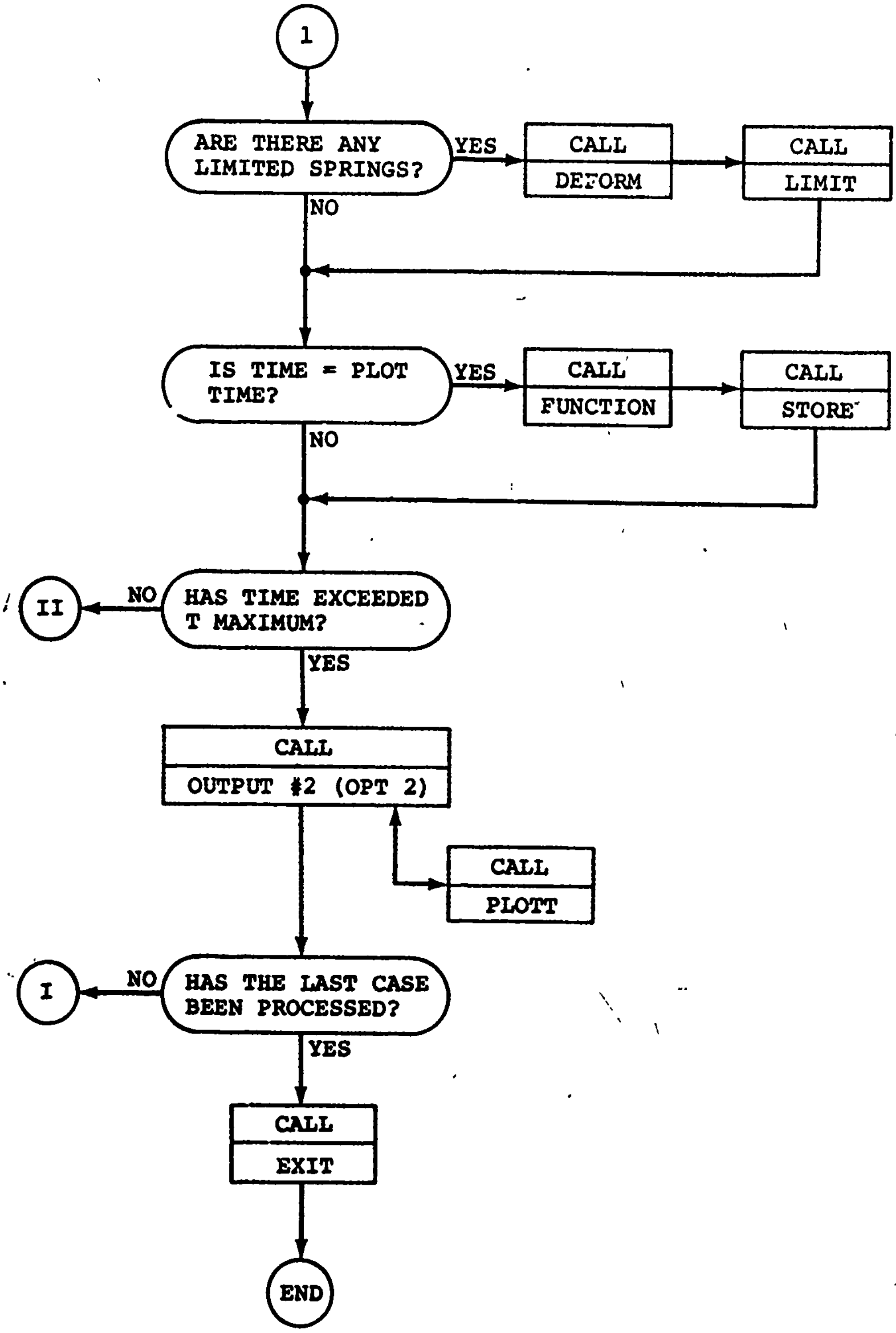
There are 129 parameters, any of which can be requested to appear in the form of a printer plot (described in tabular form in the Output Description section herein). Up to three parameters may be plotted simultaneously for comparison.

> <u>Note</u>: If more than one parameter is requested on the same plot, thought should be given to the expected magnitude of these parameters since the plotting subroutine automatically defines the scale factor. This scale factor will be applied to all the parameters appearing on a particular plot. Large-magnitude differences between the parameters destroy the engineering usefulness of this feature.

GENERAL FLOW DIAGRAM OF PROGRAM CRASH



GENERAL FLOW DIAGRAM OF PROGRAM CRASH (CONTD)



GENERAL DESCRIPTION OF SUBROUTINES

ITEM 1, SUBROUTINE "READ": All necessary data for the analysis of a crash configuration enters Program CRASH through this subroutine. Fixed and floating point data must be formatted for an I5 and E10.0 specification, respectively. The order of the read statements is consistent with the Input Description (next section herein). Coding sheet examples in proper format and a numerical example are provided in the sections on Input Description and Example Problem.

ITEM 2, SUBROUTINE "OPT1": All input data entered through subroutine "READ" is printed out by this subroutine. For a detailed description of its format and a numerical example, see the Output Description section and illustrations therein. This subroutine is one of four subroutines capable of outputting information to the user.

ITEM 3, SUBROUTINE "RUNGA": This subroutine executes the fourth-order Runge-Kutta method for solving first-order ordinary differential equations. The four required functional evaluations are obtained by calling subroutine "FUNCT". Briefly, this subroutine accepts the values of the dependent parameters and their derivatives at $t = t^*$ and calculates the values of the dependent parameters and their derivatives at $t = t^* + \Delta t$.

ITEM 4, SUBROUTINE "FUNCT": This subroutine contains the equations of motion for the generalized model. The transformed equations of motion are of the form

$$\frac{dX(I)}{dt} = FUNCT(I)$$

Vol. I of this report presents a more detailed description of this set of equations. Physically, this subroutine accepts the forces and moments within each of the springs of the generalized model (Figure 2) and calculates the acceleration and velocity of each mass. This subroutine supplies subroutine "RUNGA" with required information.

ITEM 5, SUBROUTINE "LDEF": Subroutine "LDEF" is the "load-deflection" subroutine. Knowing the physical characteristics of each spring of the generalized model, it accepts the relative deformation and elongation rate of each spring and calculates the forces required to produce these relative deformations. It tracks the load history of each spring so that hysteresis during unloading may be achieved. This subroutine supplies subroutine "FUNCT" with required information.

ITEM 6, SUBROUTINE "DEFORM": Subroutine DEFORM (deformation) contains the equations of kinematics of the generalized model. Given the current positions and velocities of the generalized coordinates, this subroutine calculates the relative deformation and elongation rate of each spring. This subroutine supplies subroutine "LDEF" with required information.

ITEM 7, SUBROUTINE "LIMIT": Subroutine "LIMIT" uses current spring elongation rates and relative deformations to estimate requested spring deformations 50 time increments in the future, i.e., $t_{future} = t_{current} + 50\ \Delta t$. If these estimated relative spring deformations exceed user-supplied limits, adjustments in that spring's load-deflection characteristics are made in an attempt to correct the projected excessive spring deformation. If these adjustments are not sufficient to correct the excessive spring deformation, subroutine "LIMIT" stops the numerical process, resets time and the necessary initial conditions, and recycles the program. If this occurs, subroutine "LIMIT" informs the user of the time the program was stopped and the restart time.

ITEM 8, SUBROUTINE "STORE": This subroutine stores all of the 129 possible output quantities at the requested printer plot times. A list of these quantities can be found in the Output Description section.

ITEM 9, SUBROUTINE "OPT2": This subroutine first prints out the results previously set aside in subroutine "STORE" with the exception of the ground displacements X_{21}, X_{22}, and X_{23}. This digital output is not optional. Second, this subroutine sorts out the results as directed by the user-supplied "plot codes" and presents the data in the proper sequence to subroutine "PLOTT". This output display is a user's option. (Further details are provided in the Output Description section.) Third, this subroutine sorts out the load-deflection history of those springs which have had their deformation restricted and presents this information in the proper sequence for digital output display. This output display is not a user's option.

ITEM 10, SUBROUTINE "PLOTT": This subroutine can accept up to three dependent one-dimensional arrays and simultaneously plot their elements against an evenly incremented, independent array. In our case, the independent array is composed of the plot times stipulated by the user and the dependent arrays are the desired calculated results as stipulated by the user-supplied "plot codes". Up to three curves may be requested simultaneously on one plot (see Output Description section). No scale factors are required, as the length of the plot is determined by the time duration of the run and the number of time increments.

INPUT DESCRIPTION

The detailed description of the input which follows is consistent with the order in which the input is read by the computer. It is suggested that the reader simultaneously review this section with the input example provided in the Example Problem section.

The programmer has attempted whenever possible to form acronyms of the input parameters to ease the confusion. The parameter name in quotes should help the user in recognizing the computer notation acronym. All input data is floating point unless stated otherwise.

INPUT TO MAIN PROGRAM

NRUN A fixed point number informing the main program of the "number" of cases to be "run" in an uninterrupted sequence. This card should be followed by NRUN number of input cases, each describing a particular crash or aircraft.

INPUT TO SUBROUTINE "READ"

XI(I) "Initial X" generalized coordinate of the model at impact. XI(1),...XI(14) describe the height above the ground in inches of the $X_1 \ldots X_{14}$ generalized coordinates. XI(15), XI(16),...XI(20) represent the initial angles of θ_1, $\theta_2, \ldots \theta_6$ in radians (see Figure 5). These parameters are not used in the computation scheme since we are interested in relative coordinate motion; however, they are necessary for a complete description of the model.

XDI(I) "Initial Derivative" with respect to time. XDI(1), XDI(2),...XDI(14) represent the vertical impact velocity of generalized coordinates X_1, $X_2, \ldots X_{14}$ in inches/sec, and XDI(15), XDI(16),...XDI(20) represent the initial angular velocity of mass M_5, M_6, ... M_{10} in radians/sec (see Figure 5). For example, XDI(2) = 360.0 and XDI(3) = 360.0 would imply that a possible rotor and engine configuration had a 360-inch/sec velocity at impact. The user is reminded here that, if a pitch rate is desired at impact, the center of gravity of the aircraft and desired pitch rate must be used in a pre-run calculation to determine the XDI(I) input. Non-zero XDI(15),...XDI(20) would imply that certain portions of the aircraft were bending with respect to one another at impact, or that these portions had previously failed and acquired an angular velocity. This input must be kinematically consistent.

SD(I,J) "Spring Data". The J elements completely describe the load-deflection characteristics of spring I. There are a possible 33 springs, each requiring 8 pieces of information for its description. Refer to Figure 4 for a detailed definition of the J elements in SD(I,J). For example, SD(3,1) = 20,000, SD(3,2) = 0.5, SD(3,3) = 0.0, and SD(3,4) = 100.0, indicating that spring 3 has an elastic load-deflection slope of 20,000 pounds/inch up to a relative deformation of 0.5 inch, at which time its load-deflection slope becomes zero. If the weight of mass 3 was 1000 pounds, CM(3) = 1000.0, then spring 3 would be programmed as a 10G load limiter. SD(3,4) is set at 100.0 inches as a highly improbable deformation level, thus defining the entire load-deflection curve for the expected limits. Note that SD(23,J) through and including SD(26,J) are used to input the torsional spring data.

CL(I) A "characteristic length" in inches. Necessary to describe the model's dimensions. CL(5), CL(6),... CL(10) are identified in Figure 6.

CM(I) "Characteristic Weight" of the I mass. CM(1), CM(2), ...CM(14) represent the weight in pounds of masses M(1), M(2),...M(14) (refer to Figure 1). If any mass is omitted from the model, its CM(I) value is assigned a nominal value of one (1).

CI(I) "Characteristic" moment of "inertia" of the I mass. CI(5), CI(6),...CI(10) represent the mass moment of inertia in (in.-lb-sec^2) about their respective mass centers. If a rotational mass is omitted from the model, its CM(I) and CI(I) values are assigned a nominal value of one (1).

D(I) Model dimensions in inches. D(1) through D(4), D(6), D(8) through D(11), D(16), D(17), D(20), and D(21) are indicated by lowercase letters in Figure 6.

DT "Delta Time" increment. This is the delta time increment in seconds, used in the numerical integration scheme. The magnitude of the time increment depends on the crash conditions and properties of the model. It is suggested that the user use the example of the Example Problem section as a guide. A value of DT = 0.0001 sec (1/10 millisecond) was found to be a reasonable compromise between time required and convergence for this example.

TMAX "Time Maximum". The numerical integration process will terminate at TMAX seconds.

PLT "Plot Time". The first time, in seconds, that calculated results will be stored for output.

DPLT "Delta Plot Time". Results will be stored every DPLT seconds, starting at PLT seconds and ending at TMAX seconds. For example, if TMAX = 0.1, PLT = 0.001, and DPLT = 0.002, the results will be stored at time 0.001 second into the impact and every .002 second thereafter until the run is complete at 0.1 second.

> Note: Detailed digital output is automatically provided at these specified times; therefore, the PLT and DPLT parameters must be specified even if no printer plots are to be requested.

NPR "Number of Plots Requested". A fixed-point number informing subroutine "OPT2" how many individual plots have been requested. There is no limit on the size of NPR.

KP(I,J) "Code" for "Plotting". A fixed-point array providing instructions for plotting. Each of the 129 possible output parameters is assigned a plotting code as tabulated in the Output Description section. The dimension of KP(I,J) is KP(NPR,3). Up to three parameters may be plotted simultaneously on one plot. A brief example would be:

KP(3,1) = 41

KP(3,2) = 42

KP(3,3) = 0

The third plot would be a comparison of the acceleration time-history of masses 1 and 2. Notice that KP(3,3) = 0 tells the computer that a third possible parameter will be omitted. Additional examples are presented in the following section, Output Description.

NIS "Number of Limited Springs". NIS is a fixed-point number which tells the program the number of springs which have had limitations placed upon their relative deformation. The program is presently dimensioned for 10 limited springs.

IGR "Is Ground Rigid"? A fixed-point number specifying the ground conditions

IGR = 0 = Yes

IGR = 1 = No

If IGR is valued at 1, the program will expect the necessary ground data to follow. If IGR = 0, the ground data is assumed to be zero, thus producing an infinitely rigid ground.

ISN(I) "Limited Spring Number". A fixed-point number which indentifies the springs which have had limitations placed upon their relative deformations. The dimension of ISN is ISN(NIS). If there are two limited springs, NIS = 2, then ISN(1) and ISN(2) must be specified.

DFE(I) "Deflection Limit". This is the maximum allowable deformation in inches that spring I will be permitted. There must be NIS deflection limits specified.

DSD(I) "Delta Spring Data". If the limited spring ISN(1) exceeds the allowable maximum deformation DFE(1), the slope of the elastic portion of its load-deflection curve SD(ISN,1) is changed to SD(ISN,1) + DSD(1). Further description of ISN(I), DFE(I), and DSD(I) has been presented in the Program Description section.

GD(I,J) "Ground Data". There are three contact points between the fuselage or landing gear and the ground (see Figure 5). GD(1,J), GD(2,J), and GD(3,J) represent the respective J coefficients of a possible fourth-order polynominal describing the deflection load characteristics of contact points X_{21}, X_{22}, and X_{23}. The general form of these equations is:

$$\text{Ground Deflection} = GD(I,1)\ (\text{force}) + GD(I,2)\ (\text{force})^2 + GD(I,3)\ (\text{force})^3 + GD(I,4)\ (\text{force})^4$$

where the deflection is in inches and the force is in pounds.

OUTPUT DESCRIPTION

Four subroutines are capable of providing output information to the user. These four subroutines are:

1. Subroutine OPT1
2. Subroutine FUNCT
3. Subroutine LIMIT
4. Subroutine OPT2

Detailed descriptions of these outputs follow.

OUTPUT FROM SUBROUTINE "OPT1": Output from subroutine OPT1 consists of a tabulation of all input data. This tabulation is formatted to be self-descriptive. This output is not a user's option. This output first reviews the plotting sequence requested by the user. Notice in the example output (Figure 7) that the fifth plot has requested a comparison of plotting parameters 88, 91, and 92. This means that the input data for the fifth plot was KP(5,1) = 88, KP(5,2) = 91, KP(5,3) = 92. This will provide a printer plot comparing the relative elongation of far-coupled springs 28, 31, and 32 (see Figure 2 and Table III). The actual printer plot resulting from this instruction is shown in Figure 8. The output of subroutine OPT1 continues by discussing the limitations imposed on any springs, a detailed listing of information about each of the 14 masses, and a discussion of ground conditions. Detailed information concerning spring data follows. The notation is defined at the top of the page with listings of each of the 33 springs. This is illustrated in Figures 7 and 9.

OUTPUT FROM SUBROUTINE "FUNCT": This is an error message output feature that informs the user that he has attempted to divide by zero. This has occurred because either the weight or mass moment of inertia of one of the lumped masses is zero. It is an input error, as explained in the Input Description section.

OUTPUT FROM SUBROUTINE "LIMIT": If restrictions are placed upon the allowable deformation of certain springs, the program may find it necessary to stop and re-start in order to satisfy these imposed limitations. If this re-start cycle occurs, the user is informed of the time at which the program failed to meet these imposed limitations and the time of the re-start. This output will occur for each re-start process. This information will aid the user in obtaining an intuitive feel for the severity of the restrictions he is imposing on the problem.

AIRFRAME CRASHWORTHINESS STUDY, MODEL NO. 1

****

THE FOLLOWING PLOTS HAVE BEEN REQUESTED

PLOT NO.	PLOTTING PARAMETERS		
1	42	43	44
2	62	63	0
3	45	46	47
4	48	49	0
5	88	91	92
6	116	117	118
7	121	124	125

RELATIVE DEFORMATIONS IS RESTRICTED FOR THE FOLLOWING SPRINGS

SPRING NUMBER	RELATIVE ALLOWABLE DEFORM.	DELTA SLOPE
**********	**********	**********
3	2.50	200.00
28	3.00	300.00

LUMPED MASS NUMBER	1	2	3	4	5	6	7
WEIGHT OF MASS (LB)-	1.00	980.00	1072.00	60.00	250.00	2147.00	230.00
HALF LENGTH (IN) -	-	-	-	-	45.00	65.00	120.00
MOMENT OF INERTIA -	-	-	-	-	437.00	7833.00	2856.00
VERT POSITION (IN) -	0.0	120.00	80.00	140.00	70.00	70.00	75.00
INITIAL ANGLE (RAD)-	-	-	-	-	0.0	0.0	0.17800
VERT VELOCITY (T=0)-	240.00	240.00	240.00	240.00	240.00	240.00	240.00
ANG VELOCITY (T=0) -	-	-	-	-	0.0	0.0	0.0

	8	9	10	11	12	13	14
WEIGHT OF MASS (LB)-	2951.00	1370.00	1.00	60.00	60.00	1.00	1.00
HALF LENGTH (IN) -	45.00	45.00	0.0	-	-	-	-
MOMENT OF INERTIA -	5160.00	5727.00	1.00	-	-	-	-
VERT POSITION (IN) -	30.00	30.00	0.0	20.00	0.0	20.00	0.0
INITIAL ANGLE (RAD)-	0.0	0.0	0.0	-	-	-	-
VERT VELOCITY (T=0)-	240.00	240.00	240.00	240.00	240.00	240.00	240.00
ANG VELOCITY (T=0) -	0.0	0.0	0.0	-	-	-	-

THE GROUND IS CONSIDERED RIGID

Figure 7. Output From Subroutine "OPT1" (Tabulation of Input Data).

TABLE III. DESCRIPTION OF PLOTTING CODE USED FOR COMPUTER OUTPUT

KP(I,J) = CODE
I = Plot number
J = Number of curve on plot I; J = 1, 2, 3

CODE	OUTPUT PARAMETER	
0	Curve Omitted	
1	Vertical Deflection of Coordinate	1
2	Vertical Deflection of Coordinate	2
3	Vertical Deflection of Coordinate	3
4	Vertical Deflection of Coordinate	4
5	Vertical Deflection of Coordinate	5
6	Vertical Deflection of Coordinate	6
7	Vertical Deflection of Coordinate	7
8	Vertical Deflection of Coordinate	8
9	Vertical Deflection of Coordinate	9
10	Vertical Deflection of Coordinate	10
11	Vertical Deflection of Coordinate	11
12	Vertical Deflection of Coordinate	12
13	Vertical Deflection of Coordinate	13
14	Vertical Deflection of Coordinate	14
15	Angle of Mass Number	5
16	Angle of Mass Number	6
17	Angle of Mass Number	7
18	Angle of Mass Number	8
19	Angle of Mass Number	9
20	Angle of Mass Number	10
21	Vertical Velocity of Coordinate	1
22	Vertical Velocity of Coordinate	2
23	Vertical Velocity of Coordinate	3
24	Vertical Velocity of Coordinate	4
25	Vertical Velocity of Coordinate	5
26	Vertical Velocity of Coordinate	6
27	Vertical Velocity of Coordinate	7
28	Vertical Velocity of Coordinate	8
29	Vertical Velocity of Coordinate	9
30	Vertical Velocity of Coordinate	10
31	Vertical Velocity of Coordinate	11
32	Vertical Velocity of Coordinate	12
33	Vertical Velocity of Coordinate	13
34	Vertical Velocity of Coordinate	14

TABLE III. Continued		
CODE	OUTPUT PARAMETER	
35	Angular Velocity of Mass Number	5
36		6
37		7
38		8
39		9
40		10
41	Acceleration of Coordinate Number	1
42		2
43		3
44		4
45		5
46		6
47		7
48		8
49		9
50		10
51		11
52		12
53		13
54		14
55	Angular Acceleration of Mass Number	5
56		6
57		7
58		8
59		9
60		10
61	Elongation of Spring Number	1
62		2
63		3
64		4
65		5
67		7
68		8
70		10
71		11
72		12
73		13
74		14

TABLE III. Continued		
CODE	OUTPUT PARAMETER	
75	Elongation of Spring Number	15
76		16
77		17
78		18
79		19
80		20
81		21
82		22
83	Angular Rotation of Torsional Spring	5
84		7
85		8
86		10
87	Elongation of Far-Coupled Spring Number	27
88		28
89		29
90		30
91		31
92		32
93		33
94	Force in Spring Number	1
95		2
96		3
97		4
98		5
100		7
101		8
103		10
104		11
105		12
106		13
107		14
108		15
109		16
110		17
111		18
112		19
113		20
114		21
115		22

TABLE III. Continued		
CODE		
116 117 118 119	Movement in Torsional Spring Number	5 7 8 10
120 121 122 123 124 125 126	Force in Far-Coupled Spring Number	27 28 29 30 31 32 33
127 128 129	Vertical Displacement of Coordinate	21 22 23

OUTPUT FROM SUBROUTINE "OPT2": This subroutine first provides a detailed digital tabulation of output parameters. The format titles each of the arrays according to the generalized model (Figures 1 through 5) and lists the results at each of the requested plot-times. This output feature is not a user's option.

If any plots have been requested, the user is supplied with a combination digital and printer-scaled-plot display of the plot code parameters. An example is provided in Figure 10. The plot will be titled according to the generalized model and a digital listing on the left side of the paper. The first column is the time and the following columns are the digital values of the requested plot parameters in E format. Notice that the title identifies the curve and digital listing by assigning a plot symbol. There is no limit to the number of plots that can be requested.

DESCRIPTION OF PLOTTING PARAMETERS
(*) REPRESENTS THE REL DISP SPR 20
(=) REPRESENTS THE REL DISP SPR 31
(+) REPRESENTS THE REL DISP SPR 32

SCALE FACTOR = 0.144E 01

X(-)	Y1(*)	Y2(=)	Y3(+)
0.110E-02	0.111E-04	0.264E 00	0.264E 00
0.310E-02	0.691E-03	0.746E 00	0.745E 00
0.510E-02	0.269E-02	0.123E 01	0.122E 01
0.710E-02	0.680E-02	0.171E 01	0.170E 01
0.910E-02	0.141E-01	0.219E 01	0.217E 01
0.111E-01	0.247E-01	0.267E 01	0.264E 01
0.131E-01	0.399E-01	0.319E 01	0.310E 01
0.151E-01	0.561E-01	0.361E 01	0.356E 01
0.171E-01	0.756E-01	0.400E 01	0.401E 01
0.191E-01	0.955E-01	0.453E 01	0.446E 01
0.211E-01	0.115E 00	0.498E 01	0.491E 01
0.231E-01	0.133E 00	0.543E 01	0.536E 01
0.251E-01	0.150E 00	0.587E 01	0.581E 01
0.271E-01	0.160E 00	0.630E 01	0.625E 01
0.291E-01	0.185E 00	0.673E 01	0.669E 01
0.311E-01	0.202E 00	0.715E 01	0.713E 01
0.331E-01	0.217E 00	0.756E 01	0.756E 01
0.351E-01	0.227E 00	0.797E 01	0.800E 01
0.371E-01	0.235E 00	0.838E 01	0.844E 01
0.391E-01	0.241E 00	0.878E 01	0.888E 01
0.411E-01	0.249E 00	0.917E 01	0.930E 01
0.431E-01	0.279E 00	0.954E 01	0.970E 01
0.451E-01	0.330E 00	0.988E 01	0.101E 02
0.471E-01	0.437E 00	0.102E 02	0.104E 02
0.491E-01	0.570E 00	0.104E 02	0.106E 02
0.511E-01	0.721E 00	0.106E 02	0.109E 02
0.531E-01	0.892E 00	0.108E 02	0.111E 02
0.551E-01	0.108E 01	0.109E 02	0.112E 02
0.571E-01	0.128E 01	0.110E 02	0.114E 02
0.591E-01	0.151E 01	0.110E 02	0.115E 02
0.611E-01	0.176E 01	0.110E 02	0.116E 02
0.631E-01	0.204E 01	0.109E 02	0.116E 02
0.651E-01	0.234E 01	0.108E 02	0.116E 02
0.671E-01	0.261E 01	0.107E 02	0.115E 02
0.691E-01	0.280E 01	0.105E 02	0.115E 02
0.711E-01	0.291E 01	0.104E 02	0.115E 02
0.731E-01	0.292E 01	0.102E 02	0.115E 02
0.751E-01	0.285E 01	0.101E 02	0.115E 02
0.771E-01	0.271E 01	0.993E 01	0.115E 02
0.791E-01	0.251E 01	0.977E 01	0.114E 02
0.811E-01	0.225E 01	0.960E 01	0.114E 02
0.831E-01	0.195E 01	0.944E 01	0.113E 02
0.851E-01	0.158E 01	0.928E 01	0.112E 02
0.871E-01	0.117E 01	0.912E 01	0.111E 02
0.891E-01	0.738E 00	0.896E 01	0.111E 02
0.911E-01	0.286E 00	0.880E 01	0.110E 02
0.931E-01	-0.135E 00	0.864E 01	0.109E 02
0.951E-01	-0.530E 00	0.848E 01	0.107E 02
0.971E-01	-0.917E 00	0.832E 01	0.104E 02
0.991E-01	-0.124E 01	0.816E 01	0.104E 02

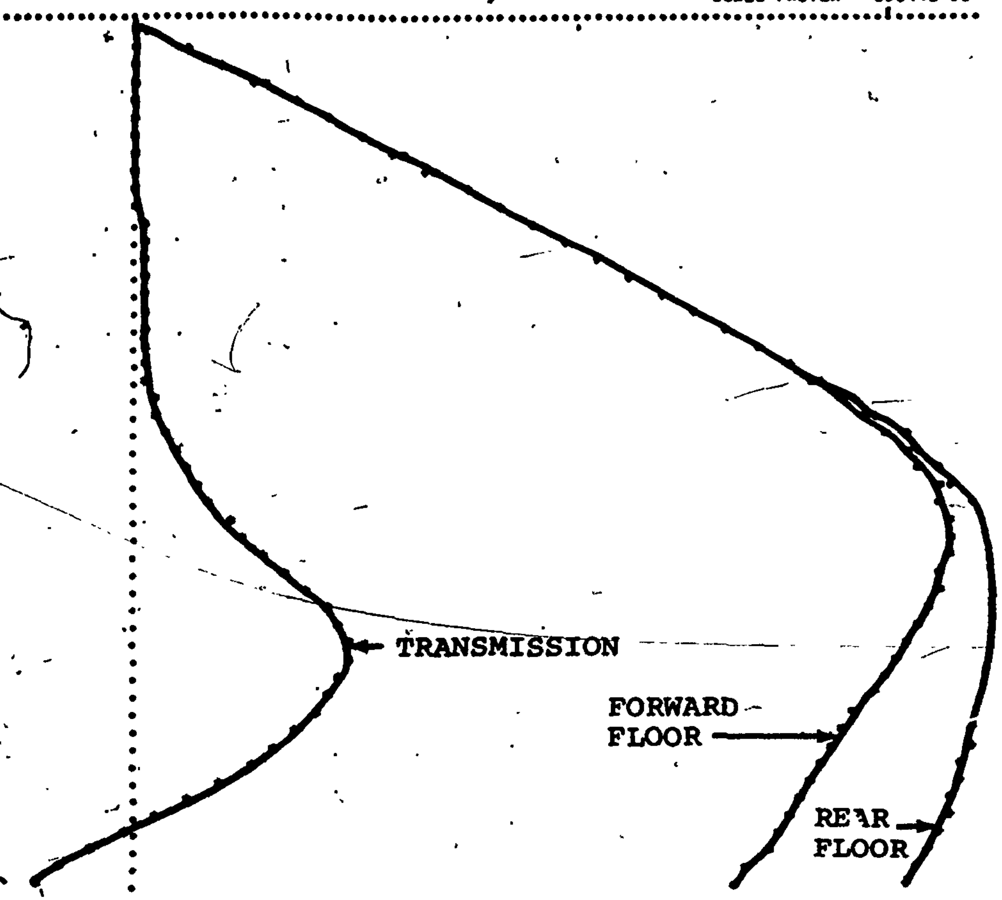


Figure 8. Computer Output (Forward Floor, Rear Floor, Transmission at 20 ft/sec Vertical Impact) Relative Displacement for UH-1D/H.

CHARACTERISTICS OF NONLINEAR SPRINGS

```
* SD(I,1)= SLOPE OF ELASTIC PORTION                  SD(I,5)= SLOPE OF SECOND PLASTIC PORTION   *
* SD(I,2)= DEFLECTION FOR YIELDING                   SD(I,6)= UNLOADING SLOPE                   *
* SD(I,3)= SLOPE OF FIRST PLASTIC PORTION            SD(I,7)= TYPE 1 , 2 IF TENSION POSSIBLE    *
* SD(I,4)= DEFLECTION TO CHANGE PLASTIC SLOPE        SD(I,8)= VISCUUS DAMPING CONSTANT          *
```

	1	2	3	4	5	6	7	8	9	10	11
SD(I,1) LB/IN -	0.0	0.0	16000.00	6000.00	6000.00	0.0	0.0	9000.00	0.0	0.0	9000.00
SD(I,2) IN -	0.0	0.0	0.50	0.50	0.50	0.0	0.0	2.00	0.0	0.0	2.00
SD(I,3) LB/IN -	0.0	0.0	-12000.00	0.0	2250.00	0.0	0.0	0.0	0.0	0.0	1000000.00
SD(I,4) IN -	0.0	0.0	1.00	100.00	4.50	0.0	0.0	8.00	0.0	0.0	100.00
SD(I,5) LB/IN -	0.0	0.0	16000.00	0.0	-4000.00	0.0	0.0	-18000.00	0.0	0.0	0.0
SD(I,6) LB/IN -	0.0	0.0	20000.00	6000.00	8000.00	0.0	0.0	12000.00	0.0	0.0	1000000.00
SD(I,7) -	0.0	0.0	1.00	1.00	1.00	0.0	0.0	2.00	0.0	0.0	2.00
SD(I,8) -	0.0	0.0	50.00	50.00	50.00	0.0	0.0	0.0	0.0	0.0	0.0
HOR. DIST. IN -	0.0	30.00	35.00	240.00	35.00	65.00	45.00	45.00	85.00	45.00	0.0

	12	13	14	15	16	17	18	19	20	21	22
SD(I,1) LB/IN -	0.0	9000.00	0.0	500000.00	75000.00	75000.00	250000.00	1000000.00	0.0	9000.00	0.0
SD(I,2) IN -	0.0	2.00	0.0	100.00	1.00	1.00	100.00	100.00	0.0	2.00	0.0
SD(I,3) LB/IN -	0.0	1000000.00	0.0	0.0	-45000.00	-45000.00	0.0	0.0	0.0	0.0	0.0
SD(I,4) IN -	0.0	100.00	0.0	0.0	2.00	2.00	0.0	0.0	0.0	8.00	0.0
SD(I,5) LB/IN -	0.0	0.0	0.0	0.0	100000.00	100000.00	0.0	0.0	0.0	-18000.00	0.0
SD(I,6) LB/IN -	0.0	1000000.00	0.0	500000.00	400000.00	400000.00	250000.00	1000000.00	0.0	12000.00	0.0
SD(I,7) -	0.0	2.00	0.0	1.00	1.00	1.00	1.00	1.00	0.0	2.00	0.0
SD(I,8) -	0.0	0.0	0.0	0.0	50.00	50.00	0.0	0.0	0.0	0.0	0.0
HOR. DIST. IN -	0.0	0.0	0.0	0.0	20.00	20.00	0.0	0.0	0.0	20.00	0.0

TORSIONAL SPRING DATA

	5	7	8	10
SD(I,1)IN-LB/R -	2000000.000	1200000.000	60000000.000	0.0
SD(I,2) RAD -	2.000	0.035	0.040	0.0
SD(I,3)IN-LB/R -	0.0	1.000	-15000000.000	0.0
SD(I,4) RAD -	0.0	0.265	0.120	0.0
SD(I,5)IN-LB/R -	0.0	-2000000.000	60000000.000	0.0
SD(I,6)IN-LB/R -	2000000.000	1200000.000	60000000.000	0.0
SD(I,7) -	1.000	1.000	2.000	0.0
SD(I,8) -	0.0	50.000	0.0	0.0

FAR COUPLED SPRINGS

	27	28	29	30	31	32	33
SD(I,1) LB/IN -	0.0	16000.000	0.0	0.0	0.0	0.0	0.0
SD(I,2) IN -	0.0	0.500	0.0	0.0	9.000	9.000	55.000
SD(I,3)LB/IN. -	0.0	-1000.000	0.0	0.0	100000.000	100000.000	1000.000
SD(I,4) IN. -	0.0	4.500	0.0	0.0	9.500	9.500	100.000
SD(I,5) LB/IN -	0.0	8000.000	0.0	0.0	40000.000	40000.000	0.0
SD(I,6) LB/IN -	0.0	20000.000	0.0	0.0	250000.000	250000.000	1000.000
SD(I,7) -	0.0	1.000	0.0	0.0	2.000	2.000	1.000
SD(I,8) -	0.0	50.000	0.0	0.0	0.0	0.0	0.0
HOR. DIST. IN.-	0.0	30.000	35.000	240.000	45.000	35.000	45.000

Figure 9. Output From Subroutine "OPT1" (Tabulation of Input Data).

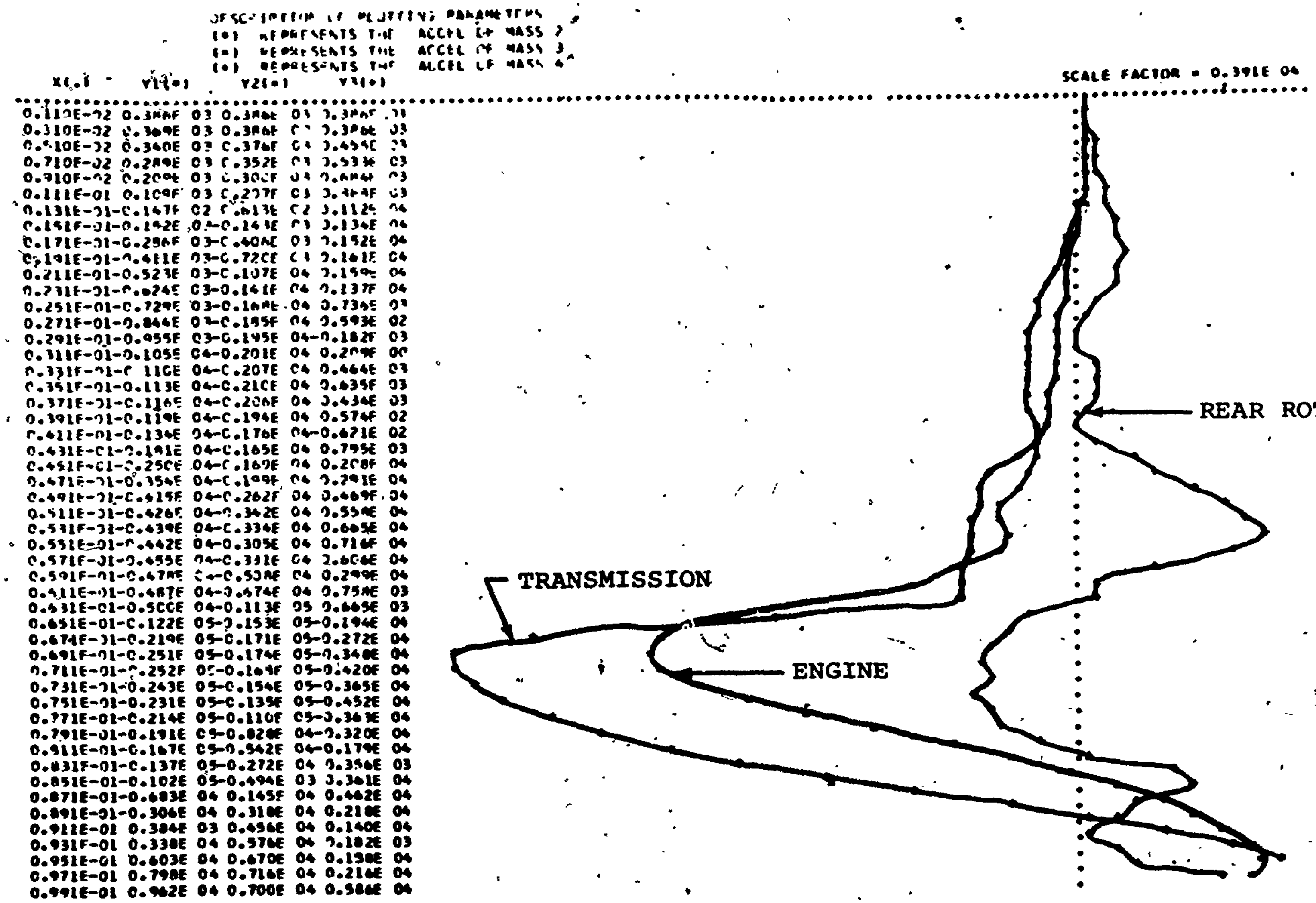


Figure 10. Computer Output (Transmission, Engine, Rotor at 20 ft/sec Vertical Impact) (Vertical Accelerations for UH-1D/H.

EXAMPLE PROBLEM

The computer simulator just discussed was used to investigate the effects of vertical impacts on a UH-1D/H helicopter. This aircraft, shown in Figure 11, is in widespread use by the Army, Air Force, and Marine Corps as a tactical transport.

Two major categories of input data were required: (1) weight data to apply to the lumped mass simulation and (2) spring constant data to apply to the various springs connecting the masses.

Information supplied by the helicopter manufacturer was used to distribute the weight in the lumped mass model. This weight distribution is shown in Table IV for the empty aircraft and for the aircraft configured as a troop carrier.

The helicopter airframe structure was mathematically represented by the system of lumped masses (Figure 12) superimposed on a general side view of the fuselage. Comparison with Figure 1 will illustrate the application of the generalized model to the UH-1D/H helicopter.

Of the 14 masses available in the model, only 10 were used to represent this aircraft. Mass (M1) was not used, since in this aircraft the engine, gearbox, and rotor are located in close proximity. Mass (M2) was used to represent the main rotor assembly, while the engine and gearbox were simulated by mass (M3). Mass (M4) depicts the tail rotor and 90-degree gearbox. The upper portion of the cockpit section was simulated by mass (M5), while mass (M6) represents the upper portion of the passenger compartment and the aft fuel cells. Mass (M7) simulates the tail-boom structure. The floor loads and the structure below the floor including the forward fuel cells were represented by masses (M8) and (M9), which were located to either side of a possible break point in the fuselage. Mass (M10) was not used, although the possibility of using it in combination with mass (M7) to simulate crushing of the tail boom was considered. However, since the tail-boom weight is small, and since in severe crashes peak floor accelerations will occur before tail-boom crushing, the effect of this mass would be negligible. Masses (M11) and (M13) were chosen to represent the landing skids. Those masses not used were assigned a weight of 1 pound.

Analysis of accident case histories involving the UH-1D/H aircraft revealed that two possible locations existed for the formation of a plastic hinge: one just forward of the main rotor and another at the juncture of the tail boom and fuselage.

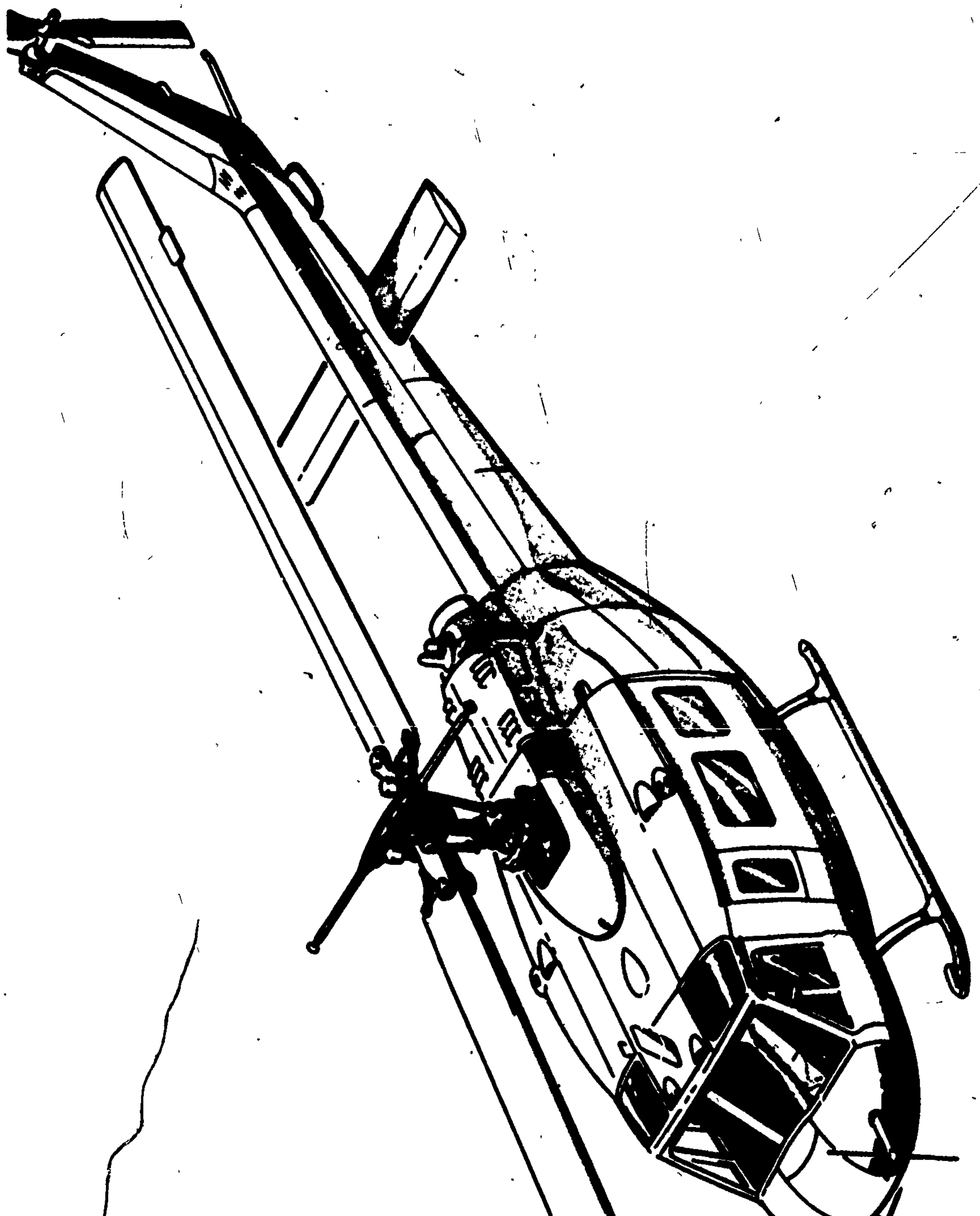


Figure 11. Helicopter Model UH-1D/H.

TABLE IV. UH-1D/H WEIGHT DISTRIBUTION			
MASS NO.	A/C EMPTY (lb)	TROOP CARRIER (lb)	TOTAL (lb)
M1	0	-	0
M2	980	-	980
M3	1047	25	1072
M4	60	-	60
M5	250	-	250
M6	847	1300	2147
M7	230	-	230
M8	1306	1645	2951
M9	270	1100	1370
M10	0	-	0
M11	60	-	60
M12	0	-	0
M13	60	-	60
M14	0	-	0
TOTALS	5110	4070	9180

The lumped mass model was therefore arranged so that these hinges were simulated between the masses at stations 110.00 and 243.89 as shown in Figure 12.

The load-deflection characteristics of the UH-1D/H airframe structure were simulated by the combinations of springs shown in Figure 13. Comparison with Figure 2 shows the application of the generalized model to this specific case.

Spring-constant data for the system were estimated by analysis of accident case histories obtained from the helicopter manufacturer and the U. S. Army Board for Aviation Accident Research (USABAAR), and by inspection of wrecked airframe structures at the U. S. Army Aeronautical Depot Maintenance Center (ARADMAC).

The main rotor and transmission in the UH-1D/H are supported by a sturdy box structure which ties directly to the floor. To simulate this structure, spring (K2) was omitted from the

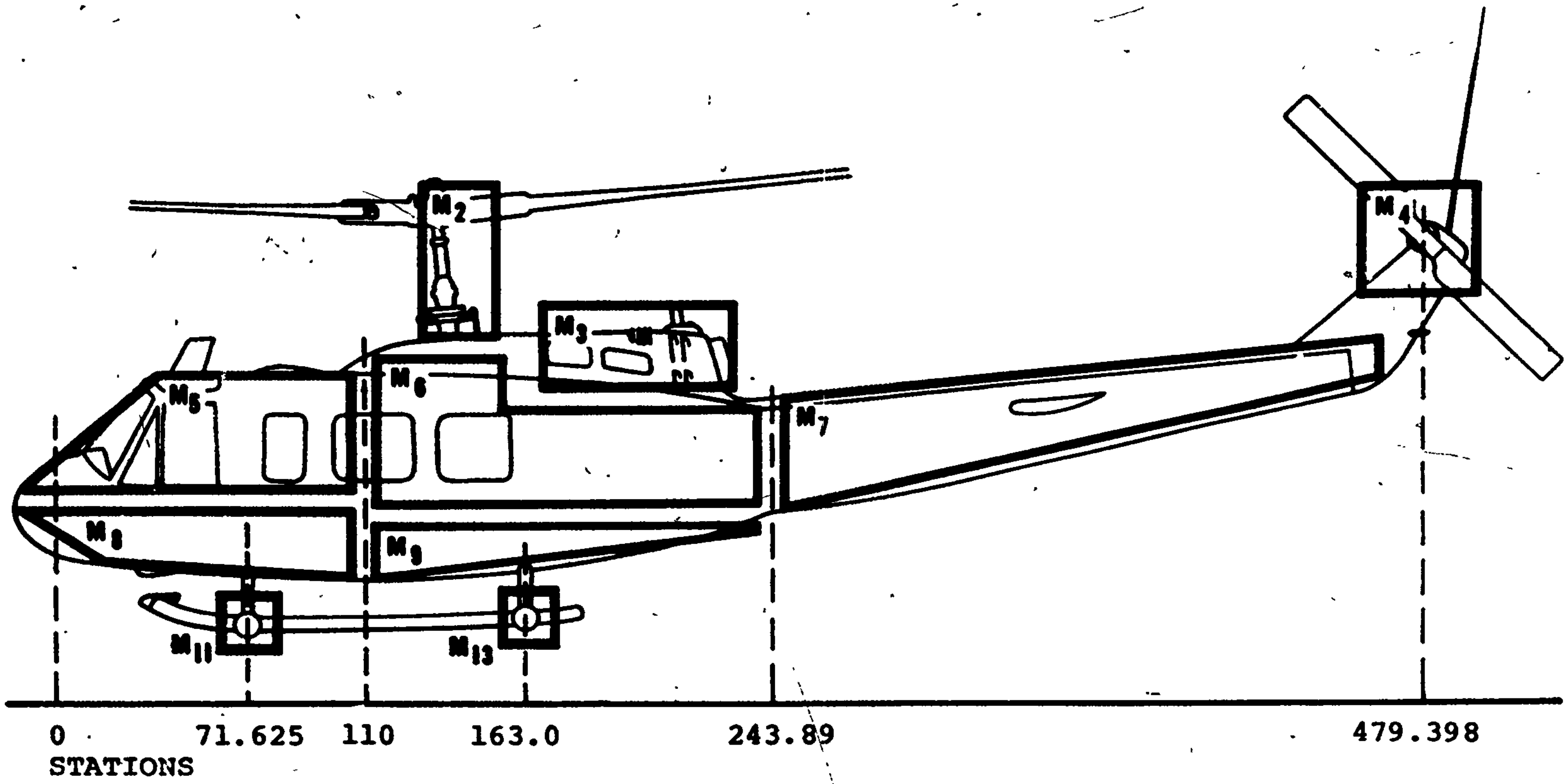


Figure 12. Lump Mass Representation of the UH-1D/H.

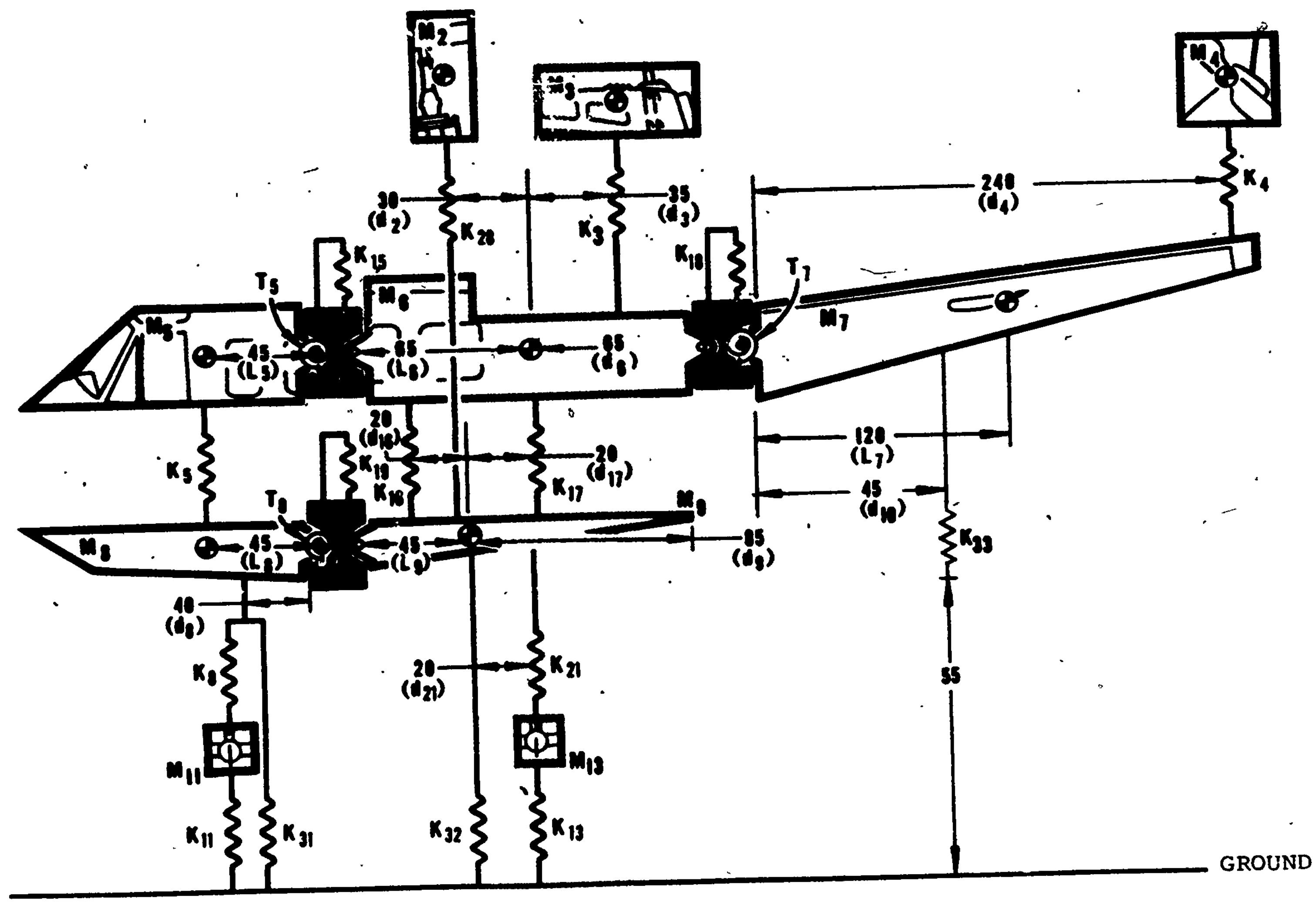


Figure 13. Load-Deflection Characteristics of UH-1D/H.

system and far-coupled spring (K28) was used to support mass (M2) at the floor, so the rotor and transmission loads would bypass the upper fuselage structure. The load-deflection characteristics of the transmission and rotor support system (Figure 14) allow approximately 1/2 inch of elastic deflection at a load of 8,000 pounds before the transmission supports fail.

The engine mass (M3) is supported by the upper fuselage section mass (M6) through spring (K3) whose load-deflection characteristics are similar to those of spring (K28), as shown in Figure 14. The sudden decrease in the load-carrying ability of springs (K3) and (K28) represents local buckling of structural members.

The displacement of the tail-boom mass (M7) is controlled by three springs: torsional spring (T7), far-coupled spring (K33), and shear spring (K18). The load-deflection characteristics of spring (T7), shown in Figure 15, permit a 2-degree rotation before a plastic hinge forms. This plastic hinge can then rotate up to 15 degrees before failure occurs, and the tail boom becomes incapable of resisting further rotation. This unlimited rotation is controlled by spring (K33), whose characteristics simulate the tail boom striking the ground after a predetermined displacement of the center of gravity of mass (M7). Shear spring (K18) is essentially rigid so that no shear deformation occurs at the hinge point.

Rotation of the forward portion of fuselage masses (M5) and (M8) about the potential plastic hinge at Station 110 (Figure 12) is controlled by torsional springs (T5) and (T8). The load-deflection characteristics of these springs are shown in Figure 15. Shear springs (K15) and (K19) control shear deformation at the hinge point. As with spring (K18), these shear springs allow no shear deformation.

The load-deflection characteristics of the landing skids are represented by two sets of springs: one for the forward portion of the skids and one for the rear portion. Each set consists of three springs: one far-coupled and two direct-coupled with springs (K8), (K11), and (K31) representing the front portion of the skids, and springs (K13), (K21), and (K32) representing the rear portion. Each of these sets allows simulation of elastic deformation, plastic deformation, skid failure, and ground contact of the fuselage. The load-deflection characteristics of these springs are presented in Figure 16.

Consider the set formed by springs (K8), (K11), and (K31). Spring (K11) allows elastic deformation up to 2 inches, with an applied load of 18,000 pounds, at which point the spring

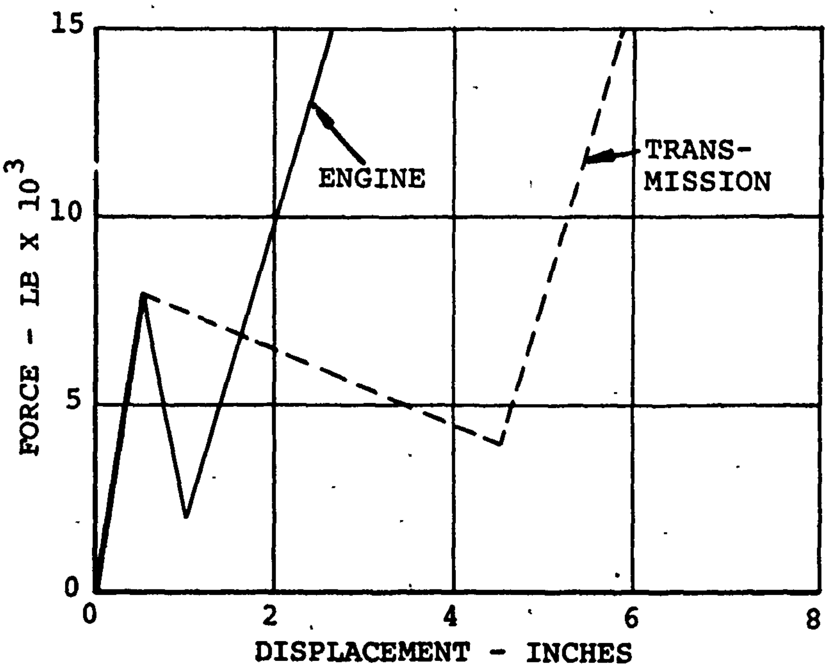


Figure 14. Load-Deflection Curve (Engine and Transmission) for UH-1D/H.

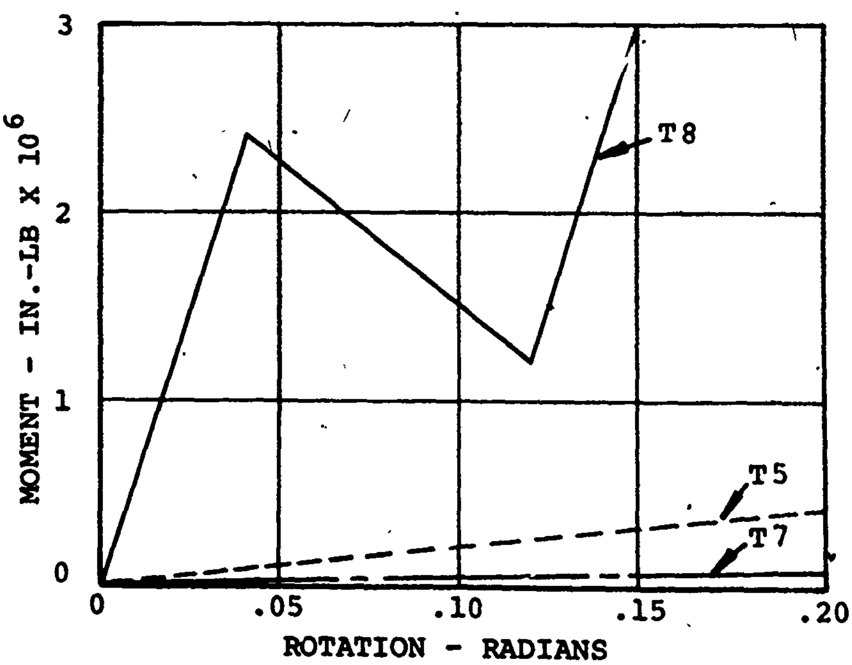


Figure 15. Load-Deflection Curves for Torsional Springs.

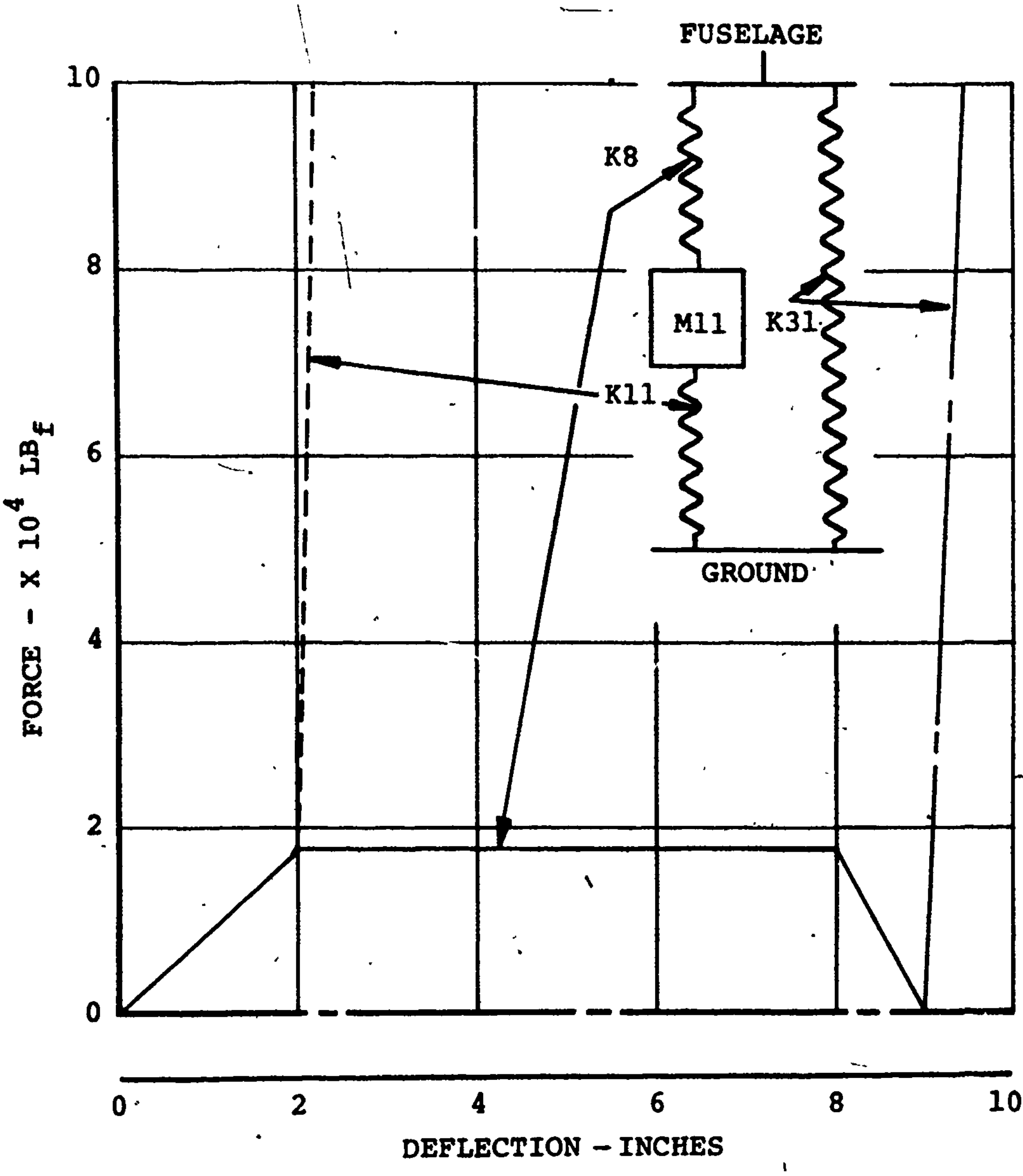


Figure 16. Load-Deflection Characteristics (Forward Landing Skid) for UH-1D/H.

becomes essentially rigid. Spring (K8) also allows elastic deformation of approximately 2 inches with an applied load of 18,000 pounds. This spring combination allows a deflection of 4 inches at a peak total load of about 36,000 pounds, or about 2G's on the 9,000-pound aircraft for each gear. Both skids then allow plastic deformation at the 36,000-pound load for an additional 7 inches. At this point the skids fail, the fuselage contacts the ground, and the influence of spring (K31) is felt. This spring represents the interaction of the fuselage and the impact surface and, therefore, carries no load until the total deflection exceeds 9 inches.

A detailed listing of the input used to simulate the UH-1D/H helicopter is shown in Figures 7 and 9.

The initial conditions for this example are a vertical impact velocity of 240 in./sec with all masses having zero angular velocity. Output of the program is also included. Figures 7 and 9 are self-descriptive output of subroutine OPT1. The complete digital output of subroutine OPT2 is omitted due to its length. Three examples of the plotting format are provided. They represent the requested plots 1 (Figure 10), 4 (Figure 17), and 5 (Figure 8) as shown in the output of Figure 7. Notice that the example has imposed restrictions on springs 3 and 28 (Figure 7). Possible load-deflection characteristics which provide results within these restrictions are provided by output (see Figure 18).

The exact input required for this example is presented in Figure 19 using the master input coding sheets included in Appendix II.

DESCRIPTION OF PLOTTING PARAMETERS
(*) REPRESENTS THE ACCEL OF MASS 8
(=) REPRESENTS THE ACCEL OF MASS 9
(+) REPRESENTS THE CURVE OMITTED

SCALE FACTOR = 0.208E 04

X(.)	V1(*)	V2(=)
0.110E-02	0.378E 03	0.147E 03
0.310E-02	0.140E 03	-0.275E 03
0.510E-02	-0.630E 02	-0.819E 03
0.710E-02	-0.124E 03	-0.123E 04
0.910E-02	-0.421E 03	-0.120E 04
0.111E-01	-0.570E 03	-0.110E 04
0.131E-01	-0.496E 03	-0.124E 04
0.151E-01	-0.445E 03	-0.101E 04
0.171E-01	-0.426E 03	-0.657E 03
0.191E-01	-0.201E 03	-0.184E 03
0.211E-01	-0.156E 03	0.142E 03
0.231E-01	-0.417E 03	-0.230E 03
0.251E-01	-0.758E 03	-0.107E 04
0.271E-01	-0.957E 03	-0.140E 04
0.291E-01	-0.736E 03	-0.972E 03
0.311E-01	-0.427E 03	-0.510E 02
0.331E-01	-0.298E 03	0.573E 03
0.351E-01	-0.410E 03	0.208E 03
0.371E-01	-0.105E 04	-0.641E 03
0.391E-01	-0.152E 04	-0.113E 04
0.411E-01	-0.442E 04	-0.819E 04
0.431E-01	-0.128E 05	-0.106E 05
0.451E-01	-0.110E 05	-0.132E 05
0.471E-01	-0.108E 05	-0.118E 05
0.491E-01	-0.127E 05	-0.714E 04
0.511E-01	-0.865E 04	-0.406E 04
0.531E-01	-0.874E 04	-0.480E 04
0.551E-01	-0.106E 05	-0.559E 04
0.571E-01	-0.885E 04	-0.126E 05
0.591E-01	-0.118E 05	-0.130E 05
0.611E-01	-0.112E 05	-0.114E 05
0.631E-01	-0.585E 04	-0.934E 04
0.651E-01	-0.103E 05	-0.943E 03
0.671E-01	-0.745E 04	0.280E 04
0.691E-01	-0.107E 04	0.153E 04
0.711E-01	-0.693E 04	0.395E 04
0.731E-01	-0.432E 04	-0.116E 04
0.751E-01	-0.461E 04	-0.534E 04
0.771E-01	-0.107E 05	-0.395E 04
0.791E-01	-0.413E 04	-0.760E 04
0.811E-01	-0.223E 04	-0.477E 04
0.831E-01	-0.255E 04	0.384E 04
0.851E-01	0.559E 04	0.134E 04
0.871E-01	-0.204E 04	0.896E 03
0.891E-01	-0.538E 04	-0.639E 03
0.911E-01	0.530E 04	-0.960E 04
0.931E-01	-0.436E 04	-0.543E 04
0.951E-01	-0.460E 04	-0.468E 04
0.971E-01	0.676E 04	-0.507E 04
0.991E-01	-0.192E 04	0.360E 04

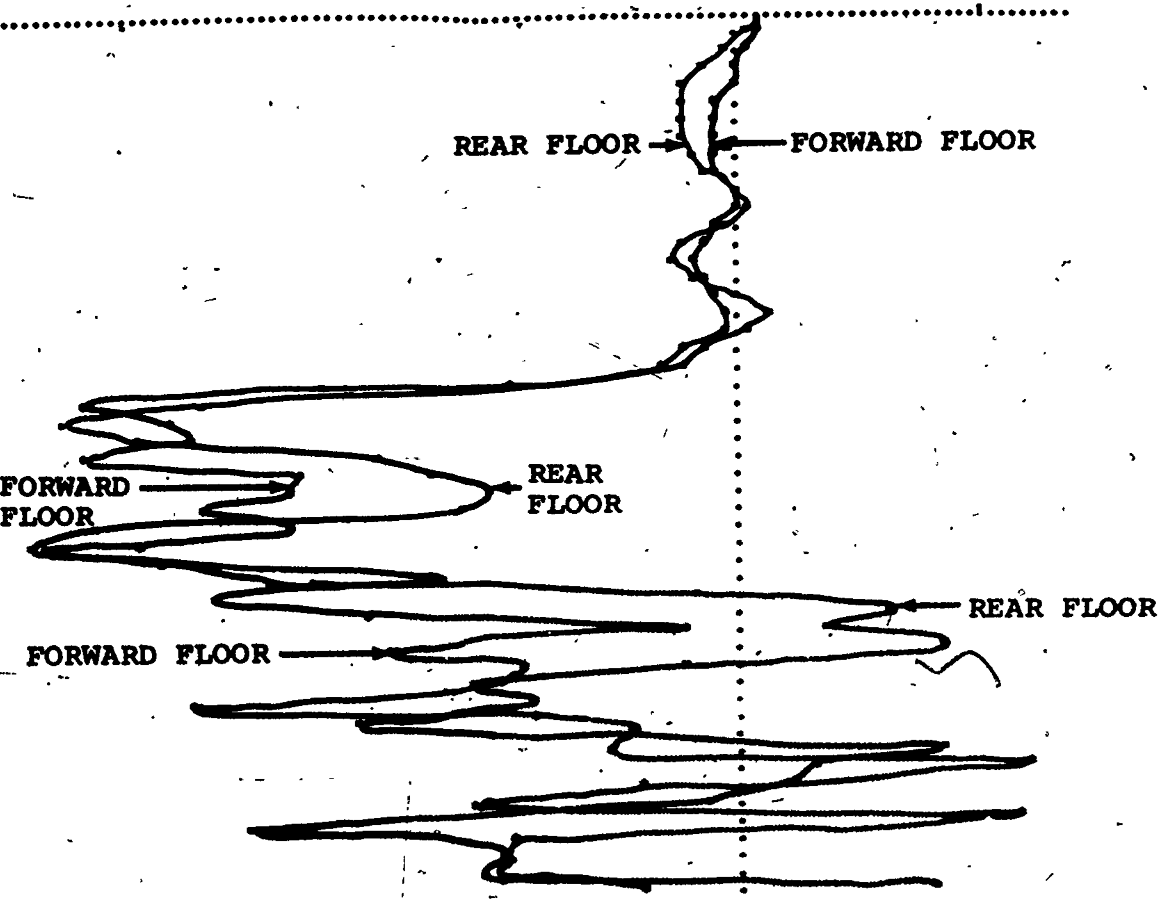


Figure 17. Computer Output (Forward Floor Hinges, Rear Floor at 20 ft/sec Vertical Impact) Vertical Accelerations for UH-1D/H.

REQUIRED LOAD-DEFLECTION CHARACTERISTICS
IMPOSED ON SPRING 3 IN ORDER NOT TO EXCEED
A DEFORMATION OF 2.50000 INCHES

FORCE(LB)	,DEFLECTION(IN)
0.222006E-03	0.139303E-07
0.664912E 00	0.405710E-04
0.707134E 01	0.441960E-03
0.315498E 02	0.197180E-02
0.949491E 02	0.593557E-02
0.225378E 03	0.140061E-01
0.453591E 03	0.283494E-01
0.907309E 03	0.504565E-01
0.130540E 04	0.919874E-01
0.195171E 04	0.121987E 00
0.273067E 04	0.170644E 00
0.359807E 04	0.224879E 00
0.445806E 04	0.278629E 00
0.519799E 04	0.324975E 00
0.575559E 04	0.359725E 00
0.614779E 04	0.384193E 00
0.642989E 04	0.401868E 00
0.663923E 04	0.414889E 00
0.674665E 04	0.421653E 00
0.668333E 04	0.418551E 00
0.640313E 04	0.404541E 00
0.634408E 04	0.396589E 00
0.534273E 04	0.376521E 00
0.602302E 04	0.385535E 00
0.632237E 04	0.426395E 00
0.797781E 04	0.510192E 00
0.625457E 04	0.645453E 00
0.392632E 04	0.839474E 00
0.343834E 04	0.108990E 01
0.796593E 04	0.137287E 01
0.129985E 05	0.166178E 01
0.255961E 05	0.194384E 01
0.379640E 05	0.219086E 01
0.459958E 05	0.237216E 01
0.491647E 05	0.247021E 01
0.485457E 05	0.247987E 01
0.469627E 05	0.240072E 01
0.436529E 05	0.223523E 01
0.387489E 05	0.199003E 01
0.325190E 05	0.167853E 01
0.253067E 05	0.132192E 01
0.178930E 05	0.947236E 00
0.108144E 05	0.593302E 00
0.449645E 04	0.277405E 00
-0.948279E 03	-0.668902E-02
-0.518492E 04	-0.271479E 00
-0.910076E 04	-0.516719E 00
-0.125713E 05	-0.733124E 00
-0.153262E 05	-0.905302E 00
-0.169220E 05	-0.100509E 01

REQUIRED LOAD-DEFLECTION CHARACTERISTICS
IMPOSED ON SPRING 28 IN ORDER NOT TO EXCEED
A DEFORMATION OF 3.00000 INCHES

FORCE(LB)	,DEFLECTION(IN)
0.191051E 00	0.113271E-04
0.110532E 02	0.690827E-03
0.430624E 02	0.269140E-02
0.108781E 03	0.679984E-02
0.225409E 03	0.140980E-01
0.395449E 03	0.247156E-01
0.620143E 03	0.387590E-01
0.898397E 03	0.561498E-01
0.120946E 04	0.755910E-01
0.152877E 04	0.955480E-01
0.183889E 04	0.114931E 00
0.212788E 04	0.132993E 00
0.240236E 04	0.150147E 00
0.268084E 04	0.167553E 00
0.296429E 04	0.185268E 00
0.323578E 04	0.202237E 00
0.346473E 04	0.216546E 00
0.363134E 04	0.226959E 00
0.375249E 04	0.234531E 00
0.385318E 04	0.240824E 00
0.398569E 04	0.249106E 00
0.446477E 04	0.279173E 00
0.541210E 04	0.338257E 00
0.698445E 04	0.436653E 00
0.793027E 04	0.569779E 00
0.777894E 04	0.721062E 00
0.760788E 04	0.992118E 00
0.74215[illegible] 04	0.107847E 01
0.7226[illegible] 04	0.127832E 01
0.699275E 04	0.150725E 01
0.673760E 04	0.176240E 01
0.646223E 04	0.203774E 01
0.243519E 05	0.233725E 01
0.530064E 05	0.260969E 01
0.609451E 05	0.280196E 01
0.634344E 05	0.291020E 01
0.636645E 05	0.291913E 01
0.622454E 05	0.284810E 01
0.595369E 05	0.271276E 01
0.554201E 05	0.250692E 01
0.503277E 05	0.225230E 01
0.442062E 05	0.194422E 01
0.367941E 05	0.157961E 01
0.287109E 05	0.117143E 01
0.200397E 05	0.737895E 00
0.110102E 05	0.286420E 00
0.250135E 04	-0.135024E 00
-0.438482E 04	-0.538143E 00
-0.104429E 05	-0.916773E 00
-0.156943E 05	-0.174490E 01

Figure 18. Required Load-Deflection Characteristics Imposed on Springs 3 and 28.

MASTER INPUT CODING FORM: PROGRAM CRASH

NROW 1

Cols 1–10	Cols 11–20	Cols 21–30	Cols 31–40	Cols 41–50	Cols 51–60	Cols 61–70	Cols 71–80
XI(1)	XI(2) 120.0	XI(3) 80.0	XI(4) 140.0	XI(5) 70.0	XI(6) 70.0	XI(7) 75.0	XI(8) 30.0
XI(9) 30.0	XI(10)	XI(11) 20.0	XI(12)	XI(13) 20.0	XI(14)	XI(15)	XI(16)
XI(17) 0.170	XI(18)	XI(19)	XI(20)	XDI(1) 240.0	XDI(2) 240.0	XDI(3) 240.0	XDI(4) 240.0
XDI(5) 240.0	XDI(6) 240.0	XDI(7) 240.0	XDI(8) 240.0	XDI(9) 240.0	XDI(10) 240.0	XDI(11) 240.0	XDI(12) 240.0
XDI(13) 240.0	XDI(14) 240.0	XDI(15)	XDI(16)	XDI(17)	XDI(18)	XDI(19)	XDI(20)
SD(1,1)	SD(1,2)	SD(1,3)	SD(1,4)	SD(1,5)	SD(1,6)	SD(1,7)	SD(1,8)
SD(2,1)	SD(2,2)	SD(2,3)	SD(2,4)	SD(2,5)	SD(2,6)	SD(2,7)	SD(2,8)
SD(3,1) 16000.	SD(3,2) 0.5	SD(3,3) -12000.	SD(3,4) 1.0	SD(3,5) 16000.	SD(3,6) 20000.	SD(3,7) 1.0	SD(3,8) 50.0
SD(4,1) 8000.	SD(4,2) 0.5	SD(4,3)	SD(4,4) 100.0	SD(4,5)	SD(4,6) 8000.	SD(4,7) 1.0	SD(4,8) 50.0
SD(5,1) 8000.	SD(5,2) 0.5	SD(5,3) 2250.	SD(5,4) 4.5	SD(5,5) -4000.	SD(5,6) 8000.	SD(5,7) 1.0	SD(5,8) 50.0
SD(6,1)	SD(6,2)	SD(6,3)	SD(6,4)	SD(6,5)	SD(6,6)	SD(6,7)	SD(6,8)
SD(7,1)	SD(7,2)	SD(7,3)	SD(7,4)	SD(7,5)	SD(7,6)	SD(7,7)	SD(7,8)
SD(8,1) 9000.	SD(8,2) 2.0	SD(8,3)	SD(8,4) 0.0	SD(8,5) -1000.	SD(8,6) 1200.	SD(8,7) 2.0	SD(8,8)
SD(9,1)	SD(9,2)	SD(9,3)	SD(9,4)	SD(9,5)	SD(9,6)	SD(9,7)	SD(9,8)
SD(10,1)	SD(10,2)	SD(10,3)	SD(10,4)	SD(10,5)	SD(10,6)	SD(10,7)	SD(10,8)
SD(11,1) 9000.	SD(11,2) 2.0	SD(11,3) 100000.	SD(11,4) 100.0	SD(11,5)	SD(11,6) 100000.	SD(11,7) 2.0	SD(11,8)
SD(12,1)	SD(12,2)	SD(12,3)	SD(12,4)	SD(12,5)	SD(12,6)	SD(12,7)	SD(12,8)
SD(13,1) 9000.	SD(13,2) 2.0	SD(13,3) 100000.	SD(13,4) 100.0	SD(13,5)	SD(13,6) 100000.	SD(13,7) 2.0	SD(13,8)
SD(14,1)	SD(14,2)	SD(14,3)	SD(14,4)	SD(14,5)	SD(14,6)	SD(14,7)	SD(14,8)
SD(15,1) 50000.	SD(15,2) 100.0	SD(15,3)	SD(15,4)	SD(15,5)	SD(15,6) 50000.	SD(15,7) 1.0	SD(15,8)
SD(16,1) 75000.	SD(16,2) 1.0	SD(16,3) -45000.	SD(16,4) 2.0	SD(16,5) 10000.	SD(16,6) 40000.	SD(16,7) 1.0	SD(16,8) 50.0
SD(17,1) 75000.	SD(17,2) 1.0	SD(17,3) -45000.	SD(17,4) 2.0	SD(17,5) 10000.	SD(17,6) 40000.	SD(17,7) 1.0	SD(17,8) 50.0
SD(18,1) 25000.	SD(18,2) 100.0	SD(18,3)	SD(18,4)	SD(18,5)	SD(18,6) 25000.	SD(18,7) 1.0	SD(18,8)
SD(19,1) 100000.	SD(19,2) 100.0	SD(19,3)	SD(19,4)	SD(19,5)	SD(19,6) 100000.	SD(19,7) 1.0	SD(19,8)
SD(20,1)	SD(20,2)	SD(20,3)	SD(20,4)	SD(20,5)	SD(20,6)	SD(20,7)	SD(20,8)
SD(21,1) 9000.	SD(21,2) 2.0	SD(21,3)	SD(21,4) 0.0	SD(21,5) -1000.	SD(21,6) 1200.	SD(21,7) 2.0	SD(21,8)
SD(22,1)	SD(22,2)	SD(22,3)	SD(22,4)	SD(22,5)	SD(22,6)	SD(22,7)	SD(22,8)
SD(23,1) 200000.	SD(23,2) 2.0	SD(23,3)	SD(23,4)	SD(23,5)	SD(23,6) 200000.	SD(23,7) 1.0	SD(23,8)
SD(24,1) 120000.	SD(24,2) 0.035	SD(24,3) 1.0	SD(24,4) .2035	SD(24,5) -200000.	SD(24,6) 120000.	SD(24,7) 1.0	SD(24,8) 50.0

Figure 19. Input for Example Problem.

MASTER INPUT CODING FORM: PROGRAM CRASH

SD(25,1) 000000000.	SD(25,2) 0.04	SD(25,3) -1150000000.	SD(25,4) 0.12	SD(25,5) 000000000.	SD(25,6) 0000000000.	SD(25,7) 2.0	SD(25,8)
SD(26,1)	SD(26,2)	SD(26,3)	SD(26,4)	SD(26,5)	SD(26,6)	SD(26,7)	SD(26,8)
SD(27,1)	SD(27,2)	SD(27,3)	SD(27,4)	SD(27,5)	SD(27,6)	SD(27,7)	SD(27,8)
SD(28,1) 10000.	SD(28,2) 0.5	SD(28,3) -10000.	SD(28,4) 4.5	SD(28,5) 10000.	SD(28,6) 20000.	SD(28,7) 1.0	SD(28,8) 50.0
SD(29,1)	SD(29,2)	SD(29,3)	SD(29,4)	SD(29,5)	SD(29,6)	SD(29,7)	SD(29,8)
SD(30,1)	SD(30,2)	SD(30,3)	SD(30,4)	SD(30,5)	SD(30,6)	SD(30,7)	SD(30,8)
SD(31,1) 0.0	SD(31,2) 0.00000	SD(31,3) 1000000.	SD(31,4) 0.50	SD(31,5) 4000.	SD(31,6) 250000.	SD(31,7) 2.0	SD(31,8)
SD(32,1) 0.0	SD(32,2) 9.00000	SD(32,3) 1000000.	SD(32,4) 0.50	SD(32,5) 4000.	SD(32,6) 250000.	SD(32,7) 2.0	SD(32,8)
SD(33,1)	SD(33,2) 55.0	SD(33,3) 1000.	SD(33,4) 100.	SD(33,5)	SD(33,6) 1000.	SD(33,7) 1.0	SD(33,8)
				CL(5) 45.0	CL(6) 85.0	CL(7) 120.0	CL(8) 45.0
CL(9) 45.0	CL(10)						
CM(1) 1.0	CM(2) 980.0	CM(3) 1972.0	CM(4) 00.0	CM(5) 250.0	CM(6) 2147.0	CM(7) 230.0	CM(8) 2951.0
CM(9) 1370.0	CM(10) 1.0	CM(11) 00.0	CM(12) 00.0	CM(13) 1.0	CM(14) 1.0		
				CI(5) 437.0	CI(6) 7033.0	CI(7) 2050.0	CI(8) 5100.0
CI(9) 5727.0	CI(10) 1.0						
D(1)	D(2) 30.0	D(3) 35.0	D(4) 240.0		D(6) 85.0		D(8) 45.0
D(9) 95.0	D(10) 45.0	D(11)	D(16) 20.0	D(17) 20.0			D(20)
D(21) 20.0							
DT 0.00011	TMAX 0.110	PLT 0.0001	DPLT 3.0002				

NPR 7	KP(1,1) 42	KP(1,2) 63	KP(1,3) 44	KP(2,1) 02	KP(2,2) 15	KP(2,3)	KP(3,1) 45	KP(3,2) 0	KP(3,3) 47	KP(4,1) 40	KP(4,2) 40	KP(4,3)	KP(5,1) 00	KP(5,2) 01	KP(5,3) 12
KP(6,1) 110	KP(6,2) 117	KP(6,3) 110	KP(7,1) 121	KP(7,2) 124	KP(7,3) 125	KP(8,1)	KP(8,2)	KP(8,3)	KP(9,1)	KP(9,2)	KP(9,3)	KP(NPR,1)	KP(NPR,2)	KP(NPR,3)	

NIS 2	IGR

ISN(1) 3	DPS(1) 2.5	DSD(1) 2000.0	NIS CARDS
ISN(2) 20	DPS(2) 3.0	DSD(2) 3000.0	
ISN(3)	DPS(3)	DSD(3)	
ISN(4)	DPS(4)	DSD(4)	ADD AS REQUIRED

GD(1,1)	GD(1,2)	GD(1,3)	GD(1,4)	IF IGR = 0, THESE CARDS ARE OMITTED
GD(2,1)	GD(2,2)	GD(2,3)	GD(2,4)	
GD(3,1)	GD(3,2)	GD(3,3)	GD(3,4)	

Figure 19. Contd.

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0001                SUBROUTINE OPTI                                                          OPTI0001
0002                COMMON ALKK,PHD,STAR,EQ,PLUS,T,DT,PLT,TMAX,DPLT,NS,NP,IRUN,              OPTI0002
                   1A(33),CI(10),CL(10),CM(14),CX(20),D(22),DF(33),DZF(33),F(40),           OPTI0003
                   1FS(33),MM(33),PDF(33),PFS(33),RV(33),SD(33,8),SX(20),VX(23),IGR,        OPTI0004
                   1X(23),XDI(23),XI(23),XT(22),Z(22),ZT(22),P(129,52),KP(20,3),NPR,        OPTI0005
                   1FD(33),PT(100),NRUN,CW(14),ISN(10),DFE(10),DSD(10),NIS,NE,GD(3,4)      OPTI0006
            C                                                                                OPTI0007
            C         THIS SUBROUTINE PRINTS OUT THE INPUT DATA.                             OPTI0008
            C                                                                                OPTI0009
0003                PRINT 89                                                                 OPTI0010
0004                PRINT 88                                                                 OPTI0011
0005                      DO 10 I=1,NPR                                                      OPTI0012
0006             10 PRINT 205,I,(KP(I,J),J=1,3)                                              OPTI0013
0007                   IF (NIS) 20,20,25                                                     OPTI0014
0008             20 PRINT 22                                                                 OPTI0015
0009                GO TO 80                                                                 OPTI0016
0010             25 PRINT 30                                                                 OPTI0017
0011                      DO 35 I=1,NIS                                                      OPTI0018
0012             35 PRINT 40,ISN(I),DFE(I),DSD(I)                                            OPTI0019
0013             80 PRINT 100                                                                OPTI0020
0014                PRINT 110                                                                OPTI0021
0015                PRINT 120                                                                OPTI0022
0016                PRINT 90, (CW(I),I=5,7),(CL(I),I=5,7),(CI(I),I=5,7),(XI(I),I=1,7),      OPTI0023
                   1(XI(I),I=15,17),(XL(I),I=1,7),(XDI(I),I=15,17)                          OPTI0024
0017                PRINT 130                                                                OPTI0025
0018                PRINT 120                                                                OPTI0026
0019                PRINT 91 ,(CW(I),I=8,14),(CL(I),I=8,10),(CI(I),I=8,10),                 OPTI0027
                   1(XI(I),I=8,14),(XI(I),I=18,20),(XDI(I),I=8,14),(XDI(I),I=18,20)        OPTI0028
0020                   IF(IGR) 82,82,81                                                      OPTI0029
0021             81 PRINT 125,((GD(I,J),J=1,4),I=1,3)                                        OPTI0030
0022                   GO TO 83                                                              OPTI0031
0023             82 PRINT 135                                                                OPTI0032
0024             83 CONTINUE                                                                 OPTI0033
0025                PRINT 140                                                                OPTI0034
0026                PRINT 150                                                                OPTI0035
0027                PRINT 160,((SD(I,J),I=1,11),J=1,8),(D(I),I=1,11)                         OPTI0036
0028                PRINT 170                                                                OPTI0037
0029                PRINT 160,((SD(I,J),I=12,22),J=1,8),(D(I),I=12,22)                       OPTI0038
0030                PRINT 190                                                                OPTI0039
0031                PRINT 200                                                                OPTI0040
0032                PRINT 180,((SD(I,J),I=23,26),J=1,8)                                      OPTI0041
0033                PRINT 210                                                                OPTI0042
0034                PRINT 220                                                                OPTI0043
0035                PRINT 185,((SD(I,J),I=27,33),J=1,8),(D(I),I=1,4),D(8),D(9),D(10)        OPTI0044
            C                                                                                OPTI0045
            C         FORMAT STATEMENTS                                                      OPTI0046
            C                                                                                OPTI0047
0036             22 FORMAT(10X,39HNO RELATIVE DEFORMATIONS ARE RESTRICTED)                   OPTI0048
0037             30 FORMAT(10X,39HRELATIVE DEFORMATIONS IS RESTRICTED FOR/                   OPTI0049
                   110X,21HTHE FOLLOWING SPRINGS//,                                          OPTI0050
                   *15X,10H    SPRING,5X,10H  RELATIVE,5X,10H  DELTA    /                    OPTI0051
                   *15X,10H    NUMBER,5X,10H ALLOWABLE,5X,10H  SLOPE    /                    OPTI0052
                   *30X,10H   DEFORM./15X,10(1H*),5X,10(1H*),5X,10(1H*))                     OPTI0053
0038             40 FORMAT(15X,I10   ,5X,F10.2,5X,F10.2)                                     OPTI0054
0039             88 FORMAT(10X,39HTHE FOLLOWING PLOTS HAVE BEEN REQUESTED//15X,              OPTI0055
                   18HPLOT NO.,5X,19HPLOTTING PARAMETERS)                                    OPTI0056
0040             89 FORMAT(1H1,20X,43HAIRFRAME CRASHWORTHINESS STUDY, MODEL NO. 1/           OPTI0057
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                121X,43(1H*))                                                     OPT10058
0041         90 FORMAT(9X,20HWEIGHT OF MASS (LB)-,7F10.2/9X,20HHALF LENGTH   (IN) OPT10059
                1-,4X,1H-,3(9X,1H-),5X,3F10.2/9X,20HMOMENT OF INERTIA  -,         OPT10060
                14X,1H-,3(9X,1H-),5X,3F10.2/9X,20HVERT POSITION (IN) -7F10.2/9X,  OPT10061
                120HINITIAL ANGLE (RAD)-,4X,1H-,3(9X,1H-),5X,3F10.5/9X,           OPT10062
                120HVERT VELOCITY (T=0)-,7F10.2/9X,20HANG VELOCITY (T=0) -,       OPT10063
                14X,1H-,3(9X,1H-),5X,3F10.2///)                                   OPT10064
0042         91 FORMAT(9X,20HWEIGHT OF MASS (LB)-,7F10.2/9X,20HHALF LENGTH   (IN) OPT10065
                1-,        3F10.2,4X,1H-,3(9X,1H-)/9X,20HMOMENT OF INERTIA  -,    OPT10066
                1         3F10.2,4X,1H-,3(9X,1H-)/9X,20HVERT POSITION (IN) -7F10.2/9XOPT10067
                1,20HINITIAL ANGLE (RAD)-,         3F10.5,4X,1H-,3(9X,1H-)/9X,    OPT10068
                120HVERT VELOCITY (T=0)-,7F10.2/9X,20HANG VELOCITY (T=0) -,       OPT10069
                1         3F10.2,4X,1H-,3(9X,1H-)///)                             OPT10070
0043        100 FORMAT(1X,/30X,20HLUMPED MASS NUMBER  )                           OPT10071
0044        110 FORMAT(34X,1H1,9X,1H2,9X,1H3,9X,1H4,9X,1H5,9X,1H6,9X,1H7)         OPT10072
0045        120 FORMAT(29X,80(1H-))                                               OPT10073
0046        125 FORMAT(20X,36HFOURTH ORDER GROUND COEFFICIENTS ARE//15X,          OPT10074
                110H FORCE    ,10H FORCE**2 ,10H FORCE**3 ,10H FORCE**4 /10X,     OPT10075
                15HX(21),4E10.3/10X,5HX(22),4E10.3/10X,5HX(23),4E10.3)            OPT10076
0047        130 FORMAT(34X,1H8,9X,1H9,9X2H10,8X,2H11,8X,2H12,8X,2H13,8X,2H14)     OPT10077
0048        135 FORMAT(   ,30HTHE GROUND IS CONSIDERED RIGID)                     OPT10078
0049        140 FORMAT(   ,10X,36HCHARACTERISTICS OF NONLINEAR SPRINGS/5X,99(1H*)/OPT10079
                15X,47H*  SD(I,1)= SLOPE OF ELASTIC PORTION            *          OPT10080
                15X,47H   SD(I,5)= SLOPE OF SECOND PLASTIC PORTION   */,          OPT10081
                15X,47H*  SD(I,2)= DEFLECTION FOR YIELDING             *          OPT10082
                15X,47H   SD(I,6)= UNLOADING SLOPE                   */,          OPT10083
                15X,47H*  SD(I,3)= SLOPE OF FIRST PLASTIC PORTION      *          OPT10084
                15X,47H   SD(I,7)= TYPE 1 , 2 IF TENSION POSSIBLE    */,          OPT10085
                15X,47H*  SD(I,4)= DEFLECTION TO CHANGE PLASTIC SLOPE *           OPT10086
                15X,47H   SD(I,8)= VISCOUS DAMPING CONSTANT          */,          OPT10087
                15X,99(1H*))                                                      OPT10088
0050        150 FORMAT(24X,1H1,9X,1H2,9X,1H3,9X,1H4,9X,1H5,9X,1H6,9X,1H7,9X,1H8,  OPT10089
                19X,1H9,9X,2H10,8X,2H11/19X,110(1H-))                             OPT10090
0051        160 FORMAT(4X,16HSD(I,1)  LB/IN -,11F10.2/4X,16HSD(I,2)  IN    -,     OPT10091
                111F10.2/4X,16HSD(I,3)  LB/IN -,11F10.2/4X,16HSD(I,4)  IN    -,   OPT10092
                111F10.2/4X,16HSD(I,5)  LB/IN -,11F10.2/4X,16HSD(I,6)  LB/IN -,   OPT10093
                111F10.2/4X,16HSD(I,7)         -,11F10.2/,                        OPT10094
                ,4X,16HSD(I,8)          -,11F10.2/,4X,16HHOR. DIST. IN  -,        OPT10095
                111F10.2///)                                                      OPT10096
0052        170 FORMAT(24X,2H12,8X,2H13,8X,2H14,8X,2H15,8X,2H16,8X,2H17,8X,2H18,  OPT10097
                18X,2H19,8X,2H20,8X,2H21,8X,2H22/19X,110(1H-))                    OPT10098
0053        180 FORMAT(4X,16HSD(I,1)IN-LB/R -, 4F13.3/4X,16HSD(I,2) RAD    -,     OPT10099
                1 4F13.3/4X,16HSD(I,3)IN-LB/R -, 4F13.3/4X,16HSD(I,4) RAD    -,   OPT10100
                1 4F13.3/4X,16HSD(I,5)IN-LB/R -, 4F13.3/4X,16HSD(I,6)IN-LB/R -,   OPT10101
                14F13.3/4X,16HSD(I,7)          -,4F13.3/4X,16HSD(I,8)        -,   OPT10102
                14F13.3//)                                                        OPT10103
0054        185 FORMAT(4X,16HSD(I,1) LB/IN  -, 7F12.3/4X,16HSD(I,2)  IN    -,     OPT10104
                1 7F12.3/4X,16HSD(I,3)LB/IN.  -, 7F12.3/4X,16HSD(I,4) IN.    -,   OPT10105
                1 7F12.3/4X,16HSD(I,5)  LB/IN -, 7F12.3/4X,16HSD(I,6) LB/IN  -,   OPT10106
                17F12.3/4X,16HSD(I,7)         -,7F12.3/4X,16HSD(I,8)        -,    OPT10107
                17F12.3/4X,16HHOR. DIST.  IN.-,7F12.3//)                          OPT10108
0055        190 FORMAT(30X,22HTORSIONAL SPRING DATA )                             OPT10109
0056        200 FORMAT(26X,1H5,11X,1H7,11X,1H8,11X,2H10/23X,50(1H-))              OPT10110
0057        205 FORMAT(18X,I5,10X,3I5)                                            OPT10111
0058        210 FORMAT(30X,19HFAR COUPLED SPRINGS)                                OPT10112
0059        220 FORMAT(26X,2H27,11X,2H28,11X,2H29,11X,2H30,11X,2H31,11X,2H32,     OPT10113
                111X,2H33/23X,85(1H-))                                            OPT10114
0060            RETURN                                                            OPT10115
                                                                                  OPT10116
0061            END
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0001                SUBROUTINE RUNGA                                                          RUNG0001
0002                DIMENSION RK1X(20),RK1Z(20),RK2X(20),RK2Z(20),RK3X(20),RK3Z(20),          RUNG0002
                   1RK4X(20),RK4Z(20),DRKX(20),DRKZ(20)                                       RUNG0003
0003                COMMON BLNK,PRD,STAR,EQ,PLUS,T,DT,PLT,TMAX,DPLT,NS,NP,IRUN,               RUNG0004
                   1A(33),CI(10),CL(10),CM(14),CX(20),D(22),DF(33),DZF(33),F(40),             RUNG0005
                   1FS(33),MM(33),PU(33),PFS(33),RV(33),SD(33,8),SX(20),VX(23),IGR,           RUNG0006
                   1X(23),XD1(23),XI(23),XT(22),Z(22),ZT(22),P(129,52),KP(20,3),NPP,          RUNG0007
                   1FO(33),PT(100),NRUN,CW(14),ISN(10),DFE(10),DSD(10),NIS,NE,GD(3,4)         RUNG0008
          C                                                                                   RUNG0009
          C            BASIC RUNGA KUTTA ROUTINE,REQUIRES SUBROUTINE                          RUNG0010
          C            FUNCT WHICH DESCRIBES THE FUNCTIONS TO BE SOLVED.                      RUNG0011
          C            NE IS THE NUMBER OF EQUATIONS                                          RUNG0012
          C                                                                                   RUNG0013
0004                DO 5 I = 1,NE                                                             RUNG0014
0005                XT(I) = X(I)                                                              RUNG0015
0006              5 ZT(I)=VX(I)                                                               RUNG0016
0007                CALL FUNCT                                                                RUNG0017
0008                DO 10 I = 1,NE                                                            RUNG0018
0009                J = I + NE                                                                RUNG0019
0010                RK1X(I) = DT*F(I)                                                         RUNG0020
0011                RK1Z(I) = DT*F(J)                                                         RUNG0021
0012                X(I) = XT(I) + RK1X(I)/2.                                                 RUNG0022
0013             10 VX(I)=ZT(I)+RK1Z(I)/2.                                                    RUNG0023
0014                CALL FUNCT                                                                RUNG0024
0015                DO 20 I = 1,NE                                                            RUNG0025
0016                J = I + NE                                                                RUNG0026
0017                RK2X(I) = DT* F(I)                                                        RUNG0027
0018                RK2Z(I) = DT* F(J)                                                        RUNG0028
0019                X(I) = XT(I) + RK2X(I)/2.                                                 RUNG0029
0020             20 VX(I)=ZT(I)+RK2Z(I)/2.                                                    RUNG0030
0021                CALL FUNCT                                                                RUNG0031
0022                DO 30 I = 1,NE                                                            RUNG0032
0023                J = I + NE                                                                RUNG0033
0024                RK3X(I) = DT * F(I)                                                       RUNG0034
0025                RK3Z(I) = DT * F(J)                                                       RUNG0035
0026                X(I) = XT(I) + RK3X(I)                                                    RUNG0036
0027             30 VX(I)=ZT(I)+RK3Z(I)                                                       RUNG0037
0028                CALL FUNCT                                                                RUNG0038
0029                DO 40 I = 1,NE                                                            RUNG0039
0030                J = I + NE                                                                RUNG0040
0031                RK4X(I) = DT * F(I)                                                       RUNG0041
0032             40 RK4Z(I) = DT * F(J)                                                       RUNG0042
0033                DO 50 I = 1,NE                                                            RUNG0043
0034                DRKX(I) = (RK1X(I)+2.*RK2X(I)+2.*RK3X(I)+RK4X(I))/6.                      RUNG0044
0035                DRKZ(I) = (RK[illegible]Z(I)+2.*RK3Z(I)+RK4Z(I))/6.                       RUNG0045
0036                X(I)=XT(I)+[illegible](I)                                                 RUNG0046
0037             50 VX(I)=ZT(I)+DRKZ(I)                                                       RUNG0047
0038                RETURN                                                                    RUNG0048
0039                END                                                                       RUNG0049
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              SUBROUTINE FUNCT
0001          COMMON BLNK,PRD,STAR,EQ,PLUS,T,DT,PLT,TMAX,DPLT,NS,NP,IRUN,
0002         1A(33),CI(10),CL(10),CM(14),CX(20),D(22),DF(33),DZF(33),F(40),
             1FS(33),MM(33),PDF(33),PFS(33),RV(33),SD(33,8),SX(20),VX(23),IGR,
             1X(23),XOI(23),XI(23),XT(22),Z(22),ZT(22),P(129,52),KP(20,3),NPR,
             1FD(33),PT(100),NRUN,CW(14),ISN(10),DFE(10),DSD(10),NIS,NE,GD(3,4)
        C
        C        GIVEN ALL THE FORCES,THIS SUBROUTINE CALCULATES
        C        THE FUNCTIONAL VALUE OF THE TRANSFORMED EQUATIONS
        C
0003          CALL LDEF
0004                DO 10 I=1,NS
0005       10 A(I)=FS(I)+FD(I)
0006                DO 20 I=1,4
0007       20 F(I)=-A(I)-A(I+26)+CW(I)
0008          F(5)=A(1)-A(5)-A(15)+CW(5)
0009          F(6)=A(2)+A(3)+A(10)+A(15)-A(16)-A(17)+CW(6)
0010          F(7)=A(6)-A(7)-A(10)+CW(7)
0011          F(8)=A(5)-A(8)-A(19)-A(31)+CW(8)+A(27)
0012          F(9)=A(16)+A(17)+A(19)+A(22)-A(20)-A(21)-A(32)+CW(9)+A(2)+A(3)
0013          F(10)=A(7)-A(10)-A(22)-A(33)+CW(10)+A(30)
0014          F(11)=A(8)-A(11)+CW(11)
0015          F(12)=A(20)-A(12)+CW(12)
0016          F(13)=A(21)-A(13)+CW(13)
0017          F(14)=A(10)-A(14)+CW(14)
0018          F(15)=A(15)*CL(5)-A(1)*(CL(5)-D(1))*CX(15)-A(23)
0019          F(16)=A(17)*(D(17)-CL(9)+CL(6))*CX(16)-A(16)*(D(16)+CL(9)-CL(6))*
             1CX(16)-A(18)*D(6)*CX(16)+
             1A(15)*CL(6)*CX(16)+A(2)*D(2)*CX(16) -A(3)*D(3)*CX(16)
0020          F(17)=A(18)*CL(7)*CX(17)-A(6)*(CL(7)-D(6))*CX(17,-A(24)
0021          F(18)=A(5)*(CL(5)-CL(8))*CX(18)+A(19)*CL(8)*CX(18)-A(25)
             1+(CL(8)-D(8))*A(8)*CX(19)+(CL(8)-D(8))*A(31)*CX(18)
             1-A(27)*(CL(8)-D(1))*CX(18)
0022          F(19)=(A(19)*CL(9)+A(1. D(16)-A( )*D(17)-A(22)*D (9)-A(20)*
             1D(20)+A(21)*D(21)-D(11)*A( ) *CX (9)+((CL(9)-CL(6))*D(2))
             1*A(2)*CX(19)-(D(3)-(CL(9)-CL( )A(3)*CX(19)
0023          F(20)=(A(22)*CL(10)+A(7)*(CL( )- (10))*CX(20)-A(26)
             1+(CL(10)-D(10))*A(10)*CX(20)+ CL( )-D(10))*A(33)*CX(20)
             1+(CL(10)-D(10))*A(10)*CX(20)+(CL(10)-D(10))*A(33)*CX(20)
             1-A(30)*(CL(10)-D(4))*CX(20)
0024                DO 30 I=1,14
0025             IF(CW(I)) 32,32,30
0026       32 PRINT 60
0027          CALL EXIT
0028       30 F(I)=F(I)/CW(I)
        C
        C        FUNCTIONAL VALUES ARE CORRECTED DUE TO PRESENTS
        C        OF SECOND DERIVATIVE , REFER TO SECTION 3.2
        C
0029                DO 35 I=15,20
0030             IF(CI(I-10))34,34,35
0031       34 PRINT 70
0032          CALL EXIT
0033       35 F(I)=F(I)/CI(I-10)
0034          F(5)=F(5)+CL(5)*VX(15)*VX( 5)*SX( 5)-CL(5)*F( 5)*CX(15)
0035          F(7)=F(7)+CL(7)*VX(17)*VX(17)*SX(17)-CL(7)*F(17)*CX(17)
0036          F(8)=F(8)+CL(8)*VX(18)*VX(18)*SX(18)-CL(8)*F(18)*CX(18)
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0037              F(10)=F(1C)+CL(10)*VX(20)*VX(20)*S (20)-CL(10)*F(20).CX(20)            FUNT0058
0038                      DO 40 I=21,40                                                  FUNT0059
0039           40 F(I)=F(I-20)                                                           FUNT0060
0040                      DO 50 I=1,20                                                   FUNT0061
0041           50 F(I)=VX(I)                                                             FUNT0062
0042              RETURN                                                                 FUNT0063
0043           60 FORMAT(1X,29HCM(I)=0.0 IN SUBROUTINE FUNCT)                             FUNT0064
0044           70 FORMAT(1X,29HC(I)=0.0 IN SUBROUTINE FUNCT)                              FUNT0065
0045              END                                                                    FUNT0066
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```
0001            SUBROUTINE LDEF                                                  LDEF0001
0002            COMMON BLNK,PRD,STAR,EQ,PLUS,T,DT,PLT,TMAX,DPLT,NS,NP,IRUN,     LDEF0002
               1A(33),CI(10),CL(10),CM(14),CX(20),D(22),DF(33),DZF(33),F(40),   LDEF0003
               1FS(33),MM(33),PDF(33),PFS(33),RV(33),SD(33,8),SX(20),VX(23),IGR, LDEF0004
               1X(23),XDI(23),XI(23),XT(22),Z(22),ZT(22),P(129,52),KP(20,3),NPR, LDEF0005
               1FD(33),PT(100),NRUN,CW(14),ISN(10),DFE(10),DSD(10),NIS,NE,GD(3,4) LDEF0006
          C                                                                      LDEF0007
          C        GIVEN THE VALUE OF THE RELATIVE DEFORMATION,THIS             LDEF0008
          C        SUBROUTINE CALCULATES THE FORCE IN EACH SPRING DUE           LDEF0009
          C        TO THE GIVEN LOAD-DEFLECTION CURVE AND THE ADDITIONAL        LDEF0010
          C        FORCE DUE TO VISCOUS DAMPING                                 LDEF0011
          C                                                                      LDEF0012
0003            CALL DEFORM                                                      LDEF0013
0004                    DO 170 I=1,NS                                            LDEF0014
0005                IF (SD(I,7)-0.1) 165,165,105                                 LDEF0015
0006         105    IF(DF(I)-PDF(I)) 100,10,10                                   LDEF0016
0007          10 IF(DF(I)-SD(I,2))20,20,30                                       LDEF0017
0008          20 FS(I)=SD(I,1)*DF(I)                                             LDEF0018
0009             GO TO 90                                                        LDEF0019
0010          30 IF(DF(I)-SD(I,4))40,40,50                                       LDEF0020
0011          40 FS(I)=SD(I,3)*DF(I)+SD(I,2)*(SD(I,1)-SD(I,3))                   LDEF0021
0012                GO TO 80                                                     LDEF0022
0013          50 FS(I)=SD(I,5)*DF(I)+SD(I,4)*(SD(I,3)-SD(I,5))+SD(I,2)*(SD(I,1)  LDEF0023
               1-SD(I,3))                                                        LDEF0024
0014                GO TO 80                                                     LDEF0025
0015          80    IF(FS(I)) 85,85,90                                           LDEF0026
0016          85 FS(I)=0.0                                                       LDEF0027
0017          90 MM(I)=1                                                         LDEF0028
0018             PFS(I)=FS(I)                                                    LDEF0029
0019             PDF(I)=DF(I)                                                    LDEF0030
0020             GO TO 170                                                       LDEF0031
0021         100 IF(MM(I)-1)110,110,120                                          LDEF0032
0022         110 DZF(I)=(SD(I,6)*PDF(I)-PFS(I))/SD(I,6)                          LDEF0033
0023         120 IF(DF(I)-DZF(I))140,140,130                                     LDEF0034
0024         130 MM(I)=2                                                         LDEF0035
0025             FS(I)=SD(I,6)*DF(I)+PFS(I)-SD(I,6)*PDF(I)                       LDEF0036
0026             GO TO 170                                                       LDEF0037
0027         140 IF(SD(I,7)-1.5)160,160,150                                      LDEF0038
0028         150 FS(I)=0.0                                                       LDEF0039
0029             GO TO 170                                                       LDEF0040
0030         160 FS(I)=SD(I,1)*(DF(I)-DZF(I))                                    LDEF0041
0031                GO TO 170                                                    LDEF0042
0032         165 FS(I)=0.0                                                       LDEF0043
0033         170 CONTINUE                                                        LDEF0044
0034                    DO 230 I=1,NS                                            LDEF0045
0035                IF( ABS(SD(I,1))-1.) 180,190,190                             LDEF0046
0036         180    IF(DF(I)-SD(I,2)) 200,190,190                                LDEF0047
0037         190    IF( ABS(FS(I))-1.) 200,220,220                               LDEF0048
0038         200 FD(I)=0.0                                                       LDEF0049
0039                GO TO 230                                                    LDEF0050
0040         220 FD(I)=SD(I,8)*RV(I)                                             LDEF0051
0041         230 CONTINUE                                                        LDEF0052
0042                IF(IGR)260,260,240                                           LDEF0053
0043         240        DO 250 I=1,3                                             LDEF0054
0044         250 X(I+20)=FS(30+I)*(GD(I,1)+FS(30+I)*(GD(I,2)+FS(30+I)*(GD(I,3)  LDEF0055
               1+FS(30+I)*(GD(I,4)))))                                           LDEF0056
0045         260 RETURN                                                          LDEF0057
0046             END                                                             LDEF0058
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DOS FORTRAN IV 360N-FO-479 3-1          MAINPGM          DATE   08/23/70     TIME   18.15.42      PAGE 0001

0001            SUBROUTINE DEFORM                                                      DEFR0001
0002            COMMON BLNK,PRO,STAR,EQ,PLUS,T,DT,PLT,TMAX,DPLT,NS,NP,IRUN,            DEFR0002
               1A(33),CI(10),CL(10),CM(14),CK(20),D(22),DF(33),D2F(33),F(40),          DEFR0003
               1FS(33),MM(33),P3F(33),PFS(33),RV(33),SD(33,8),SX(20),VX(23),IGA,       DEFR0004
               1X(23),XDT(23),XI(23),XT(22),Z(22),ZT(22),P(129,52),KP(20,3),NPR,       DEFR0005
               2FD(33),PT(100),MRUN,CW(14),ISN(10),DFE(10),DSD(10),NIS,NE,GD(3,4)      DEFR0006
          C                                                                            DEFR0007
          C        GIVEN THE CURRENT POSITIONS AND VELOCITIES OF THE                  DEFR0008
          C        GENERALIZED COORDINATES THIS SUBROUTINE CALCULATES                 DEFR0009
          C        THE RELATIVE DEFORMATION  AND RELATIVE VELOCITY OF                 DEFR0010
          C        EACH SPRING.                                                       DEFR0011
          C                                                                            DEFR0012
0003                DO 10 I=15,20                                                      DEFR0013
0004            SX(I)= SIN(X(I))                                                       DEFR0014
0005         10 CX(I)= COS(X(I))                                                       DEFR0015
          C                                                                            DEFR0016
          C        RELATIVE DEFORMATIONS                                               DEFR0017
          C                                                                            DEFR0018
0006            DF(1) =(X(1)-X(5)-D(1)*SX(15))                                         DEFR0019
0007            DF(2)= X(2)-X(6)-D(2)*SX(16)                                           DEFR0020
0008            DF(3)= X(3)-X(6)+D(3)*SX(16)                                           DEFR0021
0009            DF(4)= X(4)-X(7)-D(4)*SX(17)                                           DEFR0022
0010            DF(5)= X(5)-X(8)+CL(5)*(SX(15)-SX(18))                                 DEFR0023
0011            DF(7)= X(7)-X(10)+CL(7)*(SX(17)-SX(20))                                DEFR0024
0012            DF(8)=X(8)-X(11)+D (8)*SX(18)                                          DEFR0025
0013            DF(10)= X(10)+D (10)*SX(20)-X(14)                                      DEFR0026
0014            DF(11)=X(11)                                                           DEFR0027
0015            DF(12)=X(12)                                                           DEFR0028
0016            DF(13)=X(13)                                                           DEFR0029
0017            DF(14)=X(14)                                                           DEFR0030
0018            DF(15)=X(5)-X(6)-CL(6)*SX(16)                                          DEFR0031
0019            DF(16)=X(6)-X(9)+D(16)*(SX(16)-SX(19))                                 DEFR0032
0020            DF(17)=X(6)-X(9)+D(17)*(SX(19)-SX(16))                                 DEFR0033
0021            DF(18)=X(7)-X(6)+ D(6)*SX(16)                                          DEFR0034
0022            DF(19)=X(8)-X(9)-CL(9)*SX(19)                                          DEFR0035
0023            DF(20)=X(9)+D(20)*SX(19)-X(12)                                         DEFR0036
0024            DF(21)=X(9)-D(21)*SX(19)-X(13)                                         DEFR0037
0025            DF(22)=X(10)-X(9)+ D(9)*SX(19)                                         DEFR0038
0026            DF(23)=X(15)                                                           DEFR0039
0027            DF(24)=X(17)                                                           DEFR0040
0028            DF(25)=X(18)                                                           DEFR0041
0029            DF(26)=X(20)                                                           DEFR0042
0030            DF(27)=X(2)-X(8)-D(1)*SX(18)                                           DEFR0043
0031            DF(28)=X(2)-X(9)-D(2)*SX(19)                                           DEFR0044
0032            DF(29)=X(3)-X(9)+D(3)*SX(19)                                           DEFR0045
0033            DF(30)=X(4)-X(10)-D(4)*SX(20)                                          DEFR0046
0034            DF(31)=X(8)+D(8)*SX(18)                                                DEFR0047
0035            DF(32)=X(9)+D(11)*SX(19)                                               DEFR0048
0036            DF(33)=X(10)+D(10)*SX(20)                                              DEFR0049
          C                                                                            DEFR0050
          C        RELATIVE VELOCITIES                                                 DEFR0051
          C                                                                            DEFR0052
0037            RV(1)=VX(1)-VX(5)-D(1)*VX(15)*CX(15)                                   DEFR0053
0038            RV(2)=VX(2)-VX(6)-D(2)*VX(16)*CX(16)                                   DEFR0054
0039            RV(3)=VX(3)-VX(6)+D(3)*VX(16)*CX(16)                                   DEFR0055
0040            RV(4)=VX(4)-VX(7)-D(4)*VX(17)*CX(17)                                   DEFR0056
0041            RV(5)=VX(5)-VX(8)+CL(5)*(VX(15)*CX(15)-VX(18)*CX(18))                  DEFR0057
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      RV(7)=VX(7)-VX(10)*CL(7)*(VX(17)*CX(17)-VX(20)*CX(20))
      RV(8)=VX(8)-VX(11)*D (8)*VX(18)*CX(18)
      RV(10)=VX(10)-VX(14)*D (10)*VX(20)*CX(20)
      RV(11)=VX(11)
      RV(12)=VX(12)
      RV(13)=VX(13)
      RV(14)=VX(14)
      RV(15)=VX(5)-VX(6)-CL(6)*VX(16)*CX(16)
      RV(16)=VX(6)-VX(9)*U(16)*(VX(16)*CX(16)-VX(19)*CX(19))
      RV(17)=VX(6)-VX(9)*U(17)*(VX(19)*CX(19)-VX(16)*CX(16))
      RV(18)=VX(7)-VX(6)*CL(6)*VX(16)*CX(16)
      RV(19)=VX(8)-VX(9)-CL(9)*VX(19)*CX(19)
      RV(20)=VX(9)-VX(12)*D(20)*VX(19)*CX(19)
      RV(21)=VX(9)-VX(13)-D(21)*VX(19)*CX(19)
      RV(22)=VX(10)-VX(9)*CL(9)*VX(19)*CX(19)
      RV(23)=VX(15)
      RV(24)=VX(17)
      RV(25)=VX(18)
      RV(26)=VX(20)
      RV(27)=VX(1)-VX(8)-D(1)*CX(18)*VX(18)
      RV(28)=VX(2)-VX(9)-D(2)*CX(19)*VX(19)
      RV(29)=VX(3)-VX(9)-D(3)*CX(19)*VX(19)
      RV(30)=VX(4)-VX(10)-D(4)*CX(20)*VX(20)
      RV(31)=VX(8)*D(8)*CX(18)*VX(18)
      RV(32)=VX(9)*D(11)*CX(19)*VX(19)
      RV(33)=VX(10)*D(12)*CX(20)*VX(20)
      RETURN
      END
```

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DOS FORTRAN IV 360N-FO-479 3-8          MAINPGM          DATE   08/23/70      TIME     18.16.26      PAGE 0001

0001              SUBROUTINE STORE                                                         STOR0001
0002              COMMON BLNK,PRD,STAR,EQ,PLUS,T,DT,PLT,TMAX,DPLT,NS,NP,IRUN,              STOR0002
                 1A(33),CI(10),CL(10),CM(14),CX(20),D(22),DF(33),DZF(33),F(40),           STOR0003
                 1FS(33),MM(33),PDF(33),PFS(33),RV(33),SD(33,8),SX(20),VX(23),IGR,        STOR0004
                 1X(23),XDI(23),XI(23),XT(22),Z(22),ZT(22),P(129,52),KP(20,3),NPR,        STOR0005
                 1FD(33),PT(100),NPUN,CW(14),ISW(10),DFE(10),DSD(10),NIS,NE,GD(3,4)       STOR0006
            C                                                                              STOR0007
            C        ALL ACCELERATIONS,VELOCITIES,DISPLACEMENTS,                           STOR0008
            C        RELATIVE DEFORMATIONS,AND SPRING FORCES ARE STORED                    STOR0009
            C                                                                              STOR0010
0003              NP=NP+1                                                                  STOR0011
0004              PT(NP)=T                                                                 STOR0012
0005                       DO 10 I=1,20                                                    STOR0013
0006              J=I+20                                                                   STOR0014
0007              K=I+40                                                                   STOR0015
0008              P(I,NP)=X(I)                                                             STOR0016
0009              P(J,NP)=VX(I)                                                            STOR0017
0010           10 P(K,NP)=F(I+20)                                                          STOR0018
0011                       DO 20 I=1,33                                                    STOR0019
0012              J=I+60                                                                   STOR0020
0013              K=I+93                                                                   STOR0021
0014              P(K,NP)=FS(I)                                                            STOR0022
0015           20 P(J,NP)=DF(I)                                                            STOR0023
0016                       DO 30 I=1,3                                                     STOR0024
0017              K=I+126                                                                  STOR0025
0018              J=I+20                                                                   STOR0026
0019           30 P(K,NP)=F(J)                                                             STOR0027
0020              RETURN                                                                   STOR0028
0021              END                                                                      STOR0029
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DOS FORTRAN IV 360N-FO-479 3-1        MAINPGM           DATE   08/23/70      TIME      18.16.52       PAGE 0001

0001              SUBROUTINE LIMIT                                                      LIMT0001
0002              DIMENSION PX(100),PVX(100),PRV(26),NF(33),PDSD(10)                    LIMT0002
0003              COMMON BLNK,PRD,STAR,EQ,PLUS,T,DT,PLT,TMAX,DPLT,NS,NP,IRUN,           LIMT0003
                 1A(33),CI(10),CL(10),CM(14),CX(20),D(22),DF(33),DZF(33),F(40),         LIMT0004
                 1FS(33),MM(33),PDF(33),PFS(33),RV(33),SD(33,8),SX(20),VX(23),IGR,      LIMT0005
                 1X(23),XDI(23),XI(23),XT(22),Z(22),ZT(22),P(129,52),KP(20,3),NPR,      LIMT0006
                 1FD(33),PT(100),NRUN,CW(14),ISN(10),DFE(20),DSD(10),NIS,NE,GD(3,4)     LIMT0007
            C                                                                           LIMT0008
            C       THIS SUBROUTINE USES THE CURRENT AND UPDATTED VALUES                LIMT0009
            C       OF VELOCITY  TO LOOK AHEAD 50 TIME INCREMENTS                       LIMT0010
            C       TO CHECK THE RELATIVE DEFORMATIONS OF THE REQUESTED                 LIMT0011
            C       SPRINGS. IF THESE RESTRICTIONS ARE EXCEEDED ADJUSTMENTS             LIMT0012
            C       IN THE LOAD DEFLECTION CURVES ARE MADE.THIS SUBROUTINE              LIMT0013
            C       RECYCLES THE PROGRAM UNTIL  THE RESTRICTED                          LIMT0014
            C       DEFORMATIONS ARE OBTAINED                                           LIMT0015
            C                                                                           LIMT0016
0004              MSW=0                                                                 LIMT0017
0005                    DO 110 I=1,NIS                                                  LIMT0018
0006              JJ=ISN(I)                                                             LIMT0019
0007                 IF(DFE(I)- ABS(DF(JJ)+50.*DT*RV(JJ))) 10,10,105                    LIMT0020
0008           10 MSW=1                                                                 LIMT0021
0009                 IF(NF(JJ)-1) 20,20,30                                              LIMT0022
0010           20 NF(JJ)=2                                                              LIMT0023
0011              PRV(JJ)=RV(JJ)                                                        LIMT0024
0012              MSW=-1                                                                LIMT0025
0013                 GO TO 110                                                          LIMT0026
0014           30    IF(NF(JJ)-50) 40,40,140                                            LIMT0027
0015           40 NF(JJ)=NF(JJ)+1                                                       LIMT0028
0016              FAC=(51-NF(JJ))*(RV(JJ)-PRV(JJ))+RV(JJ)                               LIMT0029
0017                 IF(RV(JJ)*FAC) 105,105,50                                          LIMT0030
0018           50 IF(DF(JJ)-SD(JJ,2)) 60,60,70                                          LIMT0031
0019           60 SD(JJ,1)=SD(JJ,1)+NF(JJ)*DSD(I)                                       LIMT0032
0020                 GO TO 110                                                          LIMT0033
0021           70 IF(DF(JJ)-SD(JJ,4)) 80,80,85                                          LIMT0034
0022           80 SD(JJ,3)=SD(JJ,3)+NF(JJ)*DSD(I)                                       LIMT0035
0023                 GO TO 110                                                          LIMT0036
0024           85 SD(JJ,5)=SD(JJ,5)+NF(JJ)*DSD(I)                                       LIMT0037
0025                 GO TO 110                                                          LIMT0038
0026          105 NF(JJ)=1                                                              LIMT0039
0027          110 CONTINUE                                                              LIMT0040
0028                 IF(MSW) 115,170,130                                                LIMT0041
0029          115       DO 116 I=1,NIS                                                  LIMT0042
0030              JJ=ISN(I)                                                             LIMT0043
0031                 IF(NF(JJ)-2) 116,116,170                                           LIMT0044
0032          116 CONTINUE                                                              LIMT0045
0033          117 ST=T                                                                  LIMT0046
0034                    DO 120 I=1,20                                                   LIMT0047
0035              PX(I)=X(I)                                                            LIMT0048
0036          120 PVX(I)=VX(I)                                                          LIMT0049
0037                    DO 125 I=1,NIS                                                  LIMT0050
0038          125 PDSD(I)=DSD(I)                                                        LIMT0051
0039          130 RETURN                                                                LIMT0052
0040          140 DSD(I)=2.*PDSD(I)                                                     LIMT0053
0041                    DO 150 I=1,20                                                   LIMT0054
0042              X(I)=PX(I)                                                            LIMT0055
0043          150 VX(I)=PVX(I)                                                          LIMT0056
0044                    DO 160 I=1,33                                                   LIMT0057
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DOS FORTRAN IV 360N-FO-479 3-1          LIMIT            DATE   08/23/70     TIME    10.16.52       PAGE 0002

 0045          160 NF(I)=1                                                          LINT0058
 0046              PRINT 800,T,ST                                                   LINT0059
 0047          800 FORMAT(5X,30HALL TEST HAVE FAILED AT TIME =,F13.7,               LINT0060
                  129HI HAVE RETURNED TO TIME =,F13.7)                              LINT0061
 0048              T=ST-DT                                                          LINT0062
 0049          170 RETURN                                                           LINT0063
 0050              END                                                              LINT0064
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0001          SUBROUTINE OPT2                                                   OPT20001
0002          DIMENSION PNAM(508),Y1(100),Y2(100),Y3(100),PP(3),PM(3)           OPT20002
0003          COMMON BLNK,PRD,STAR,EQ,PLUS,T,CT,PLT,TMAX,DPLT,NS,NP,IRUN,       OPT20003
             1A(33),CI(10),CL(10),CM(14),CX(20),D(22),F(33),DZF(33),F(40),      OPT20004
             1FS(33),MM(33),PDF(33),PFS(33),RV(33),SD(33,8),SX(20),VX(23),ISR,  OPT20005
             1X(23),XD1(23),XL(23),XT(22),Z(22),ZT(22),P(129,52),KP(20,3),NPR,  OPT20006
             1FD(33),PT(100),NRUN,CW(14),ISV(10),DFE(10),DSD(10),NIS,NE,GD(3,4) OPT20007
        C                                                                        OPT20008
        C       PLOT TITLES                                                      OPT20009
        C                                                                        OPT20010
0004          DATA PNAM/4HCURV,4HE OM,4HITTE,4HD    ,                           OPT20011
             14HDISP,4H OF ,4HMASS,4H  1 ,4HDISP,4H OF ,4HMASS,4H  2 ,          OPT20012
             14HDISP,4H OF ,4HMASS,4H  3 ,4HDISP,4H OF ,4HMASS,4H  4 ,          OPT20013
             14HDISP,4H OF ,4HMASS,4H  5 ,4HDISP,4H OF ,4HMASS,4H  6 ,          OPT20014
             14HDISP,4H OF ,4HMASS,4H  7 ,4HDISP,4H OF ,4HMASS,4H  8 ,          OPT20015
             14HDISP,4H OF ,4HMASS,4H  9 ,4HDISP,4H OF ,4HMASS,4H 10,           OPT20016
             14HDISP,4H OF ,4HMASS,4H 11,4HDISP,4H OF ,4HMASS,4H 12,            OPT20017
             14HDISP,4H OF ,4HMASS,4H 13,4HDISP,4H OF ,4HMASS,4H 14,            OPT20018
             14HROT.,4H OF ,4HMASS,4H  5 ,4HROT.,4H OF ,4HMASS,4H  6 ,          OPT20019
             14HROT.,4H OF ,4HMASS,4H  7 ,4HROT.,4H OF ,4HMASS,4H  8 ,          OPT20020
             14HROT.,4H OF ,4HMASS,4H  9 ,4HROT.,4H OF ,4HMASS,4H 10,           OPT20021
             14HVEL ,4H OF ,4HMASS,4H  1 ,4HVEL ,4H OF ,4HMASS,4H  2 ,          OPT20022
             14HVEL ,4H OF ,4HMASS,4H  3 ,4HVEL ,4H OF ,4HMASS,4H  4 ,          OPT20023
             14HVEL ,4H OF ,4HMASS,4H  5 ,4HVEL ,4H OF ,4HMASS,4H  6 ,          OPT20024
             14HVEL ,4H OF ,4HMASS,4H  7 ,4HVEL ,4H OF ,4HMASS,4H  8 ,          OPT20025
             14HVEL ,4H OF ,4HMASS,4H  9 ,4HVEL ,4H OF ,4HMASS,4H 10,           OPT20026
             14HVEL ,4H OF ,4HMASS,4H 11,4HVEL ,4H OF ,4HMASS,4H 12,            OPT20027
             14HVEL ,4H OF ,4HMASS,4H 13,4HVEL ,4H OF ,4HMASS,4H 14,            OPT20028
             14HANG ,4HVEL ,4HOF M,4H- 5 ,4HANG ,4HVEL ,4HOF M,4H- 6 ,          OPT20029
             14HANG ,4HVEL ,4HOF M,4H- 7 ,4HANG ,4HVEL ,4HOF M,4H- 8 ,          OPT20030
             14HANG ,4HVEL ,4HOF M,4H- 9 ,4HANG ,4HVEL ,4HOF M,4H- 10,          OPT20031
             14HACCE,4HL OF,4H MAS,4HS 1 ,4HACCE,4HL OF,4H MAS,4HS 2 ,          OPT20032
             14HACCE,4HL OF,4H MAS,4HS 3 ,4HACCE,4HL OF,4H MAS,4HS 4 ,          OPT20033
             14HACCE,4HL OF,4H MAS,4HS 5 ,4HACCE,4HL OF,4H MAS,4HS 6 ,          OPT20034
             14HACCE,4HL OF,4H MAS,4HS 7 ,4HACCE,4HL OF,4H MAS,4HS 8 ,          OPT20035
             14HACCE,4HL OF,4H MAS,4HS 9 ,4HACCE,4HL OF,4H MAS,4HS 10,          OPT20036
             14HACCE,4HL OF,4H MAS,4HS 11,4HACCE,4HL OF,4H MAS,4HS 12,          OPT20037
             14HACCE,4HL OF,4H MAS,4HS 13,4HACCE,4HL OF,4H MAS,4HS 14,          OPT20038
             14HANG ,4HACCE,4HL OF,4HM-5 ,4HANG ,4HACCE,4HL OF,4HM-6 ,          OPT20039
             14HANG ,4HACCE,4HL OF,4HM-7 ,4HANG ,4HACCE,4HL OF,4HM-8 ,          OPT20040
             14HANG ,4HACCE,4HL OF,4HM-9 ,4HANG ,4HACCE,4HL OF,4HM-10,          OPT20041
             14HREL ,4HDISP,4H SPR,4H  1 ,4HREL ,4HDISP,4H SPR,4H  2 ,          OPT20042
             14HREL ,4HDISP,4H SPR,4H  3 ,4HREL ,4HDISP,4H SPR,4H  4 ,          OPT20043
             14HREL ,4HDISP,4H SPR,4H  5 ,4HREL ,4HDISP,4H SPR,4H  6 ,          OPT20044
             14HREL ,4HDISP,4H SPR,4H  7 ,4HREL ,4HDISP,4H SPR,4H  8 ,          OPT20045
             14HREL ,4HDISP,4H SPR,4H  9 ,4HREL ,4HDISP,4H SPR,4H 10,           OPT20046
             14HREL ,4HDISP,4H SPR,4H 11,4HREL ,4HDISP,4H SPR,4H 12,            OPT20047
             14HREL ,4HDISP,4H SPR,4H 13,4HREL ,4HDISP,4H SPR,4H 14,            OPT20048
             14HREL ,4HDISP,4H SPR,4H 15,4HREL ,4HDISP,4H SPR,4H 16,            OPT20049
             14HREL ,4HDISP,4H SPR,4H 17,4HREL ,4HDISP,4H SPR,4H 18,            OPT20050
             14HREL ,4HDISP,4H SPR,4H 19,4HREL ,4HDISP,4H SPR,4H 20,            OPT20051
             14HREL ,4HDISP,4H SPR,4H 21,4HREL ,4HDISP,4H SPR,4H 22,            OPT20052
             14HREL ,4HROT.,4H SPR,4H  5 ,4HREL ,4HROT.,4H SPR,4H  7 ,          OPT20053
             14HREL ,4HROT.,4H SPR,4H  8 ,4HREL ,4HROT.,4H SPR,4H 10,           OPT20054
             14HREL ,4HDISP,4H SPR,4H 27,4HREL ,4HDISP,4H SPR,4H 28,            OPT20055
             14HREL ,4HDISP,4H SPR,4H 29,4HREL ,4HDISP,4H SPR,4H 30,            OPT20056
             14HREL ,4HDISP,4H SPR,4H 31,4HREL ,4HDISP,4H SPR,4H 32,            OPT20057
             14HREL ,4HDISP,4H SPR,4H 33,                                       OPT20058
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                  14HFORC,4HE-SP,4HRING,4H  1 ,4HFORC,4HE-SP,4HRING,4H  2 ,          OPT20059
                  14HFORC,4HE-SP,4HRING,4H  3 ,4HFORC,4HE-SP,4HRING,4H  4 ,          OPT20060
                  14HFORC,4HE-SP,4HRING,4H  5 ,4HFORC,4HE-SP,4HRING,4H  6 ,          OPT20061
                  14HFORC,4HE-SP,4HRING,4H  7 ,4HFORC,4HE-SP,4HRING,4H  8 ,          OPT20062
                  14HFORC,4HE-SP,4HRING,4H  9 ,4HFORC,4HE-SP,4HRING,4H 10,           OPT20063
                  14HFORC,4HE-SP,4HRING,4H 11,4HFORC,4HE-SP,4HRING,4H 12,            OPT20064
                  14HFORC,4HE-SP,4HRING,4H 13,4HFORC,4HE-SP,4HRING,4H 14,            OPT20065
                  14HFORC,4HE-SP,4HRING,4H 15,4HFORC,4HE-SP,4HRING,4H 16,            OPT20066
                  14HFORC,4HE-SP,4HRING,4H 17,4HFORC,4HE-SP,4HRING,4H 18,            OPT20067
                  14HFORC,4HE-SP,4HRING,4H 19,4HFORC,4HE-SP,4HRING,4H 20,            OPT20068
                  14HFORC,4HE-SP,4HRING,4H 21,4HFORC,4HE-SP,4HRING,4H 22,            OPT20069
                  14HHOME,4HNT-S,4HPRIN,4HG 5 ,4HHOME,4HNT-S,4HPRIN,4HG 7 ,          OPT20070
                  14HHOME,4HNT-S,4HPRIN,4HG 8 ,4HHOME,4HNT-S,4HPRIN,4HG 10,          OPT20071
                  14HFORC,4HE-SP,4HRING,4H 27,4HFORC,4HE-SP,4HRING,4H 28,            OPT20072
                  14HFORC,4HE-SP,4HRING,4H 29,4HFORC,4HE-SP,4HRING,4H 30,            OPT20073
                  14HFORC,4HE-SP,4HRING,4H 31,4HFORC,4HE-SP,4HRING,4H 32,            OPT20074
                  14HFORC,4HE-SP,4HRING,4H 33/                                       OPT20075
            C                                                                        OPT20076
            C        DIGITAL OUTPUT                                                  OPT20077
            C                                                                        OPT20078
0005                PRINT 908                                                        OPT20079
0006                NN=9                                                             OPT20080
0007                     DO 906 I=1,126                                              OPT20081
0008                K=4*I+4                                                          OPT20082
0009                 K1=K-3                                                          OPT20083
0010                 PRINT 907,(PNA4(JJ),JJ=K1,K)                                    OPT20084
0011                PRINT 905,(P(I,J),J=1,NP)                                        OPT20085
0012                   IF(I-NN) 906,904,904                                          OPT20086
0013            904 PRINT 908                                                        OPT20087
0014                NN=NN+9                                                          OPT20088
0015            906 CONTINUE                                                         OPT20089
            C                                                                        OPT20090
            C        PLOTTING SEQUENCE                                               OPT20091
            C                                                                        OPT20092
0016                     DO 100 I=1,NPR                                              OPT20093
0017                N1=KP(I,1)                                                       OPT20094
0018                N2=KP(I,2)                                                       OPT20095
0019                N3=KP(I,3)                                                       OPT20096
0020                   IF(N2-N3) 60,20,40                                            OPT20097
0021             20 NC=1                                                             OPT20098
0022                     DO 30 J=1,NP                                                OPT20099
0023             30 Y1(J)=P(N1,J)                                                    OPT20100
0024                N2=0                                                             OPT20101
0025                N3=0                                                             OPT20102
0026                   GO TO 80                                                      OPT20103
0027             40 NC=2                                                             OPT20104
0028                     DO 50 J=1,NP                                                OPT20105
0029                Y1(J)=P(N1,J)                                                    OPT20106
0030             50 Y2(J)=P(N2,J)                                                    OPT20107
0031                N3=0                                                             OPT20108
0032                   GO TO 80                                                      OPT20109
0033             60 NC=3                                                             OPT20110
0034                     DO 70 J=1,NP                                                OPT20111
0035                Y1(J)=P(N1,J)                                                    OPT20112
0036                Y2(J)=P(N2,J)                                                    OPT20113
0037             70 Y3(J)=P(N3,J)                                                    OPT20114
0038             80 N1=4*N1+4                                                        OPT20115
0039                N2=4*N2+4                                                        OPT20116
```

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0040            N3=4*N3+4                                                   OPT20117
0041            N11=N1-3                                                    OPT20119
0042            N22=N2-3                                                    OPT20120
0043            N33=N3-3                                                    OPT20121
0044            PRINT 800,(PNAM(JJ),JJ=N11,N1),(PNAM(JJ),JJ=N22,N2),        OPT20122
               1(PNAM(JJ),JJ=N33,N3)                                        OPT20123
0045            CALL PLOTT(NC,NP,PT,Y1,Y2,Y3,PP,PM)                         OPT20124
0046        100 CONTINUE                                                    OPT20125
      C                                                                     OPT20126
      C            REQUIRED LOAD-DEFLECTION INFORMATION DETERMINED          OPT20127
      C            BY SUBROUTINE LIMIT                                      OPT20128
      C                                                                     OPT20129
0047               IF(NIS) 140,140,110                                      OPT20130
0048       110            DO 120 I=1,NIS                                    OPT20131
0049            JJ=ISN(I)+93                                                OPT20132
0050            KK=ISN(I)+60                                                OPT20133
0051                      DO 130 II=1,NP                                    OPT20134
0052            Y1(II)=P(JJ,II)                                             OPT20135
0053        130 Y2(II)=P(KK,II)                                             OPT20136
0054            PRINT 910,ISN(I),DFE(I)                                     OPT20137
0055            PRINT 909,(Y1(J),Y2(J),J=1,NP)                              OPT20138
0056        120 CONTINUE                                                    OPT20139
0057        140 CONTINUE                                                    OPT20140
0058        800 FORMAT(1H1,23X,34HDESCRIPTION OF PLOTTING PARAMETERS/21X,   OPT20141
               121H(*)  REPRESENTS THE  ,4A4/21X,21H(=)  REPRESENTS THE     OPT20142
               14A4/21X,21H(+)  REPRESENTS THE  ,4A4)                       OPT20143
0059        905 FORMAT(1X,10E13.6)                                          OPT20144
0060        907 FORMAT(5X,4A4)                                              OPT20145
0061        908 FORMAT(1H1)                                                 OPT20146
0062        910 FORMAT(1H1,5X,40HREQUIRED LOAD-DEFLECTION CHARACTERISTICS,/5X,  OPT20147
               118HIMPOSED ON SPRING ,I5,2X,22HIN ORDER NOT TO EXCEED,/5X,  OPT20148
               117HA DEFORMATION OF ,F10.5,2X,6HINCHES,//10X,25HFORCE(LB) ,DEFLECTOPT20149
               110N(IN)//)                                                  OPT20150
0063        909 FORMAT(5X,2E13.6)                                           OPT20151
0064            RETURN                                                      OPT20152
0065            END                                                         OPT20153
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DOS FORTRAN IV 360N-FO-479 3-1          PLOTT               DATE   08/23/70      TIME      18.18.34          PAGE 0001

0001              SUBROUTINE PLOTT (M,NP,X,Y1,Y2,Y3,PP,PM)                                          PLOT0001
0002              DIMENSION PP(3),PM(3),PLOT(110),S(150),Y1(150),Y2(150),Y3(150),                   PLOT0002
                 1X(100)                                                                            PLOT0003
0003              DATA BLNK,PRD,STAR,EQ,PLUS/' ','.','*','=','+'/                                   PLOT0004
            C                                                                                       PLOT0005
            C     *-*-*-*-*-*-*---*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-PLOT0006
            C                      PLOTT PLOTS UP TO 3 DEPENDENT,CONTINOUS,                         PLOT0007
            C                      SINGLED VALUED FUNCTIONS (Y1,Y2,Y3) AGAINST                      PLOT0008
            C                      AN EVEN INCREMENTED INDEPENDENT VARIABLE(X).                     PLOT0009
            C                      M IS THE NUMBER OF DEPENDENT VARIABLES                           PLOT0010
            C                      NP IS THE DIMENSION OF THE ARRAYS X,Y1,Y2,Y3                     PLOT0011
            C     *-*-*-*-*-*-*---*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-PLOT0012
            C                                                                                       PLOT0013
0004            7 FORMAT(1X,2E10.3,4X,110A1)                                                        PLOT0014
0005            8 FORMAT(1X,3E10.3,4X,100A1)                                                        PLOT0015
0006            9 FORMAT(1X,4E10.3,4X,90A1)                                                         PLOT0016
0007          325 FORMAT(5X,4HX(.),5X,5HY1(*),89X,14HSCALE FACTOR =,E10.3)                          PLOT0017
0008          335 FORMAT(5X,4HX(.),5X,5HY1(*),5X,5HY2(=),79X,14HSCALE FACTOR =,E10.3PLOT0018
                 1)                                                                                 PLOT0019
0009          345 FORMAT(5X,4HX(.),5X,5HY1(*),5X,5HY2(=),5X,5HY3(+),69X,14HSCALE FACPLOT0020
                 1TOR =,E10.3)                                                                      PLOT0021
0010          350 FORMAT(1X,123(1H.),10H.........))                                                 PLOT0022
0011              DO 5 I=1,110                                                                      PLOT0023
0012            5 PLOT(I)=BLNK                                                                      PLOT0024
0013                        DO 6 I=1,3                                                              PLOT0025
0014              PP(I)=0.0                                                                         PLOT0026
0015            6 PM(I)=0.0                                                                         PLOT0027
            C                                                                                       PLOT0028
            C     *-*-*-*-*-*-*---*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-PLOT0029
            C                      MAX. AND MIN.VALUES OF DEPENDENT VARIABLES                       PLOT0030
            C                               ARE OBTAINED                                            PLOT0031
            C     *-*-*-*-*-*-*---*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-PLOT0032
            C                                                                                       PLOT0033
0016              DO 10 I=1,NP                                                                      PLOT0034
0017           10 S(I)=Y1(I)                                                                        PLOT0035
0018              MSW=1                                                                             PLOT0036
0019              GO TO 60                                                                          PLOT0037
0020           20 DO 30 I=1,NP                                                                      PLOT0038
0021           30 S(I)=Y3(I)                                                                        PLOT0039
0022              MSW=2                                                                             PLOT0040
0023              GO TO 60                                                                          PLOT0041
0024           40 DO 50 I=1,NP                                                                      PLOT0042
0025           50 S(I)=Y2(I)                                                                        PLOT0043
0026              MSW=3                                                                             PLOT0044
0027           60 DO 90 I=1,NP                                                                      PLOT0045
0028              IF(S(I)-PP(MSW)) 70,75,75                                                         PLOT0046
0029           70 IF(S(I)-PM(MSW)) 80,90,90                                                         PLOT0047
0030           80 PM(MSW)=S(I)                                                                      PLOT0048
0031              GO TO 90                                                                          PLOT0049
0032           75 PP(MSW)=S(I)                                                                      PLOT0050
0033           90 CONTINUE                                                                          PLOT0051
            C                                                                                       PLOT0052
            C     *-*-*-*-*-*-*---*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-PLOT0053
            C                      REFERENCE AND SCALE FACTOR ARE CALCULATED                        PLOT0054
            C     *-*-*-*-*-*-*---*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-PLOT0055
            C                                                                                       PLOT0056
0034              IF(MSW-(M-1)) 20,40,100                                                           PLOT0057
0035          100 CONTINUE                                                                          PLOT0058
```

```
      XM=0.0                                                          PLOT0059
      XMI=PP(1)                                                       PLOT0060
         DO 96 I=1,3                                                  PLOT0061
      IF(PP(I)-XM) 93,94,94                                           PLOT0062
   94 XM=PP(I)                                                        PLOT0063
   93 IF(PM(I)-XMI) 95,95,96                                          PLOT0064
   95 XMI=PM(I)                                                       PLOT0065
   96 CONTINUE                                                        PLOT0066
      S(2)=PP(2)                                                      PLOT0067
      S(3)=PM(2)                                                      PLOT0068
      PP(2)=PP(3)                                                     PLOT0069
      PM(2)=PM(3)                                                     PLOT0070
      PP(3)=S(2)                                                      PLOT0071
      PM(3)=S(3)                                                      PLOT0072
      NRA=100-(M-1)*10                                                PLOT0073
      RA=NRA                                                          PLOT0074
      SF=(XM-XMI)/RA                                                  PLOT0075
      SFT=10.*SF                                                      PLOT0076
      ZZ=XMI/(XM-XMI)                                                 PLOT0077
         IF(ZZ-1) 106,105,105                                         PLOT0078
  105 REF=RA+1.5                                                      PLOT0079
         GO TO 107                                                    PLOT0080
  106 REF= ABS(ZZ)*RA+1.5                                             PLOT0081
  107 NR=REF                                                          PLOT0082
      GO TO(320,330,340),M                                            PLOT0083
  320 PRINT 325,SFT                                                   PLOT0084
      GO TO 4                                                         PLOT0085
  330 PRINT 335,SFT                                                   PLOT0086
      GO TO 4                                                         PLOT0087
  340 PRINT 345,SFT                                                   PLOT0088
    4 PRINT 350                                                       PLOT0089
      DO 290 I=1,NP                                                   PLOT0090
      PLOT(NR)=PRD                                                    PLOT0091
      L=Y1(I)/SF+REF                                                  PLOT0092
      PLOT(L)=STAR                                                    PLOT0093
      GO TO (140,110,110),M                                           PLOT0094
  110 K=Y2(I)/SF+REF                                                  PLOT0095
      PLOT(K)=EQ                                                      PLOT0096
      IF(M-2) 150,150,120                                             PLOT0097
  120 J=Y3(I)/SF+REF                                                  PLOT0098
      PLOT(J)=PLUS                                                    PLOT0099
      GO TO 160                                                       PLOT0100
  140 PRINT 7,X(I),Y1(I),(PLOT(J),J=1,110)                            PLOT0101
      PLOT(L)=BLNK                                                    PLOT0102
      GO TO 290                                                       PLOT0103
  150 PRINT 8, X(I),Y1(I),Y2(I),(PLOT(J),J=1,100)                     PLOT0104
      PLOT(L)=BLNK                                                    PLOT0105
      PLOT(K)=BLNK                                                    PLOT0106
      GO TO 290                                                       PLOT0107
  160 PRINT 9, X(I),Y1(I),Y2(I),Y3(I),(PLOT(J),J=1,90)                PLOT0108
C                                                                     PLOT0109
C     *-*-*-*-*-*-*----*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-PLOT0110
C                   PLOT FIELD IS RE-ZEROED                           PLOT0111
C     *-*-*-*-*-*-*----*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-PLOT0112
C                                                                     PLOT0113
      DO 165 NO=1,110                                                 PLOT0114
  165 PLOT(NO)=BLNK                                                   PLOT0115
  290 CONTINUE                                                        PLOT0116
      RETURN                                                          PLOT0117
      END                                                             PLOT0118
```

APPENDIX II

MASTER INPUT CODING FORM: PROGRAM CRASH

MASTER INPUT CODING FORM: PROGRAM CRASH

NRUN

Cols 1–10	Cols 11–20	Cols 21–30	Cols 31–40	Cols 41–50	Cols 51–60	Cols 61–70	Cols 71–80
XI(1)	XI(2)	XI(3)	XI(4)	XI(5)	XI(6)	XI(7)	XI(8)
XI(9)	XI(10)	XI(11)	XI(12)	XI(13)	XI(14)	XI(15)	XI(16)
XI(17)	XI(18)	XI(19)	XI(20)	XDI(1)	XDI(2)	XDI(3)	XDI(4)
XDI(5)	XDI(6)	XDI(7)	XDI(8)	XDI(9)	XDI(10)	XDI(11)	XDI(12)
XDI(13)	XDI(14)	XDI(15)	XDI(16)	XDI(17)	XDI(18)	XDI(19)	XDI(20)
SD(1,1)	SD(1,2)	SD(1,3)	SD(1,4)	SD(1,5)	SD(1,6)	SD(1,7)	SD(1,8)
SD(2,1)	SD(2,2)	SD(2,3)	SD(2,4)	SD(2,5)	SD(2,6)	SD(2,7)	SD(2,8)
SD(3,1)	SD(3,2)	SD(3,3)	SD(3,4)	SD(3,5)	SD(3,6)	SD(3,7)	SD(3,8)
SD(4,1)	SD(4,2)	SD(4,3)	SD(4,4)	SD(4,5)	SD(4,6)	SD(4,7)	SD(4,8)
SD(5,1)	SD(5,2)	SD(5,3)	SD(5,4)	SD(5,5)	SD(5,6)	SD(5,7)	SD(5,8)
SD(6,1)	SD(6,2)	SD(6,3)	SD(6,4)	SD(6,5)	SD(6,6)	SD(6,7)	SD(6,8)
SD(7,1)	SD(7,2)	SD(7,3)	SD(7,4)	SD(7,5)	SD(7,6)	SD(7,7)	SD(7,8)
SD(8,1)	SD(8,2)	SD(8,3)	SD(8,4)	SD(8,5)	SD(8,6)	SD(8,7)	SD(8,8)
SD(9,1)	SD(9,2)	SD(9,3)	SD(9,4)	SD(9,5)	SD(9,6)	SD(9,7)	SD(9,8)
SD(10,1)	SD(10,2)	SD(10,3)	SD(10,4)	SD(10,5)	SD(10,6)	SD(10,7)	SD(10,8)
SD(11,1)	SD(11,2)	SD(11,3)	SD(11,4)	SD(11,5)	SD(11,6)	SD(11,7)	SD(11,8)
SD(12,1)	SD(12,2)	SD(12,3)	SD(12,4)	SD(12,5)	SD(12,6)	SD(12,7)	SD(12,8)
SD(13,1)	SD(13,2)	SD(13,3)	SD(13,4)	SD(13,5)	SD(13,6)	SD(13,7)	SD(13,8)
SD(14,1)	SD(14,2)	SD(14,3)	SD(14,4)	SD(14,5)	SD(14,6)	SD(14,7)	SD(14,8)
SD(15,1)	SD(15,2)	SD(15,3)	SD(15,4)	SD(15,5)	SD(15,6)	SD(15,7)	SD(15,8)
SD(16,1)	SD(16,2)	SD(16,3)	SD(16,4)	SD(16,5)	SD(16,6)	SD(16,7)	SD(16,8)
SD(17,1)	SD(17,2)	SD(17,3)	SD(17,4)	SD(17,5)	SD(17,6)	SD(17,7)	SD(17,8)
SD(18,1)	SD(18,2)	SD(18,3)	SD(18,4)	SD(18,5)	SD(18,6)	SD(18,7)	SD(18,8)
SD(19,1)	SD(19,2)	SD(19,3)	SD(19,4)	SD(19,5)	SD(19,6)	SD(19,7)	SD(19,8)
SD(20,1)	SD(20,2)	SD(20,3)	SD(20,4)	SD(20,5)	SD(20,6)	SD(20,7)	SD(20,8)
SD(21,1)	SD(21,2)	SD(21,3)	SD(21,4)	SD(21,5)	SD(21,6)	SD(21,7)	SD(21,8)
SD(22,1)	SD(22,2)	SD(22,3)	SD(22,4)	SD(22,5)	SD(22,6)	SD(22,7)	SD(22,8)
SD(23,1)	SD(23,2)	SD(23,3)	SD(23,4)	SD(23,5)	SD(23,6)	SD(23,7)	SD(23,8)
SD(24,1)	SD(24,2)	SD(24,3)	SD(24,4)	SD(24,5)	SD(24,6)	SD(24,7)	SD(24,8)

MASTER INPUT CODING FORM: PROGRAM CRASH

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
SD(25,1)	SD(25,2)	SD(25,3)	SD(25,4)	SD(25,5)	SD(25,6)	SD(25,7)	SD(25,8)
SD(26,1)	SD(26,2)	SD(26,3)	SD(26,4)	SD(26,5)	SD(26,6)	SD(26,7)	SD(26,8)
SD(27,1)	SD(27,2)	SD(27,3)	SD(27,4)	SD(27,5)	SD(27,6)	SD(27,7)	SD(27,8)
SD(28,1)	SD(28,2)	SD(28,3)	SD(28,4)	SD(28,5)	SD(28,6)	SD(28,7)	SD(28,8)
SD(29,1)	SD(29,2)	SD(29,3)	SD(29,4)	SD(29,5)	SD(29,6)	SD(29,7)	SD(29,8)
SD(30,1)	SD(30,2)	SD(30,3)	SD(30,4)	SD(30,5)	SD(30,6)	SD(30,7)	SD(30,8)
SD(31,1)	SD(31,2)	SD(31,3)	SD(31,4)	SD(31,5)	SD(31,6)	SD(31,7)	SD(31,8)
SD(32,1)	SD(32,2)	SD(32,3)	SD(32,4)	SD(32,5)	SD(32,6)	SD(32,7)	SD(32,8)
SD(33,1)	SD(33,2)	SD(33,3)	SD(33,4)	SD(33,5)	SD(33,6)	SD(33,7)	SD(33,8)
				CL(5)	CL(6)	CL(7)	CL(8)
CL(9)	CL(10)						
CM(1)	CM(2)	CM(3)	CM(4)	CM(5)	CM(6)	CM(7)	CM(8)
CM(9)	CM(10)	CM(11)	CM(12)	CM(13)	CM(14)		
				CI(5)	CI(6)	CI(7)	CI(8)
CI(9)	CI(10)						
D(1)	D(2)	D(3)	D(4)		D(6)		D(8)
D(9)	D(10)	D(11)	D(16)	D(17)			D(20)
D(21)							
DT	TMAX	PLT	DPLT				

1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	56–60	61–65	66–70	71–75	76–80
NPR	KP(1,1)	KP(1,2)	KP(1,3)	KP(2,1)	KP(2,2)	KP(2,3)	KP(3,1)	KP(3,2)	KP(3,3)	KP(4,1)	KP(4,2)	KP(4,3)	KP(5,1)	KP(5,2)	KP(5,3)
KP(6,1)	KP(6,2)	KP(6,3)	KP(7,1)	KP(7,2)	KP(7,3)	KP(8,1)	KP(8,2)	KP(8,3)	KP(9,1)	KP(9,2)	KP(9,3)	KP(NPR,1)	KP(NPR,2)	KP(NPR,3)	
NIS	IGR														

1–5	6–20	21–30	
ISN(1)	DPE(1)	DSD(1)	NIS CARDS
ISN(2)	DPE(2)	DSD(2)	
ISN(3)	DPE(3)	DSD(3)	
ISN(4)	DPE(4)	DSD(4)	ADD AS REQUIRED

1–10	11–20	21–30	31–40	
GD(1,1)	GD(1,2)	GD(1,3)	GD(1,4)	IF IGR = 0, THESE CARDS ARE OMITTED
GD(2,1)	GD(2,2)	GD(2,3)	GD(2,4)	
GD(3,1)	GD(3,2)	GD(3,3)	GD(3,4)	

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13. ABSTRACT

A mathematical model which may be used to determine the dynamic response of a helicopter airframe subjected to vertical crash loading ~~has been~~ developed.

This report is, in effect, a manual which will facilitate the use of the computer program "CRASH". The program was written to solve the equations and to handle the nonlinearities and constraints which result from use of the mathematical model.

The program was used to evaluate the response of the UH-1D/H helicopter to vertical impact loadings. Recommendations ~~have~~ been made which, when implemented, will reduce the forces transmitted to the floor and transmission of the aircraft.

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